BTEC: Computer system principles and practice

Analysis of two contrasting computer systems

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Report aim

The following report focuses on examining two contrasting computer system, with them being a general purpose computer system that is utilized specifically for CAD purposes and a CNC controller system which contains either a Fanuc or a Siemens system. With the stated systems, the report will initially analyze the hardware aspect of the systems in terms of both the internal and external hardware components utilized within them and which specifications could potentially be adequate for their respective purposes. From there, the report discusses the software systems, utilities, and application that either system uses and how said software work and enhance improve upon the core function of the system. Lastly, the report would go through the security threats that either system could face and the potential improvement that could be made in order to enhance the overall security of both systems.

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Definition and applications

By definition, a computer system refers to any pair of hardware electrical components that are utilize in unison in order to run a piece of software which is able to store information and run application and several digital command, all of which can be manipulated and utilized by an end-user.

As such the following report will discuss and analyze to contrasting computer systems utilized for different purposes and applications, one of which being a conventional computer used in running Computer Aided Design (CAD) software, with the other being a computer system used in operating an industrial manufacturing machine known as a Computer Numerical Control or CNC.

CAD computers:

Definition:

CAD, the abbreviation to Computer Aided Design, is a piece of software application that is utilized in designing component and models of objects digitally in both three and two dimensions, which provides designers and engineers with much greater freedom during the designing process as it allows them to intricately add very small components and details that would conventionally be inefficient to add if the process were to be done physically on a piece of paper. Additionally, due to files in which the models are stored all being digital, they can be easily shared and transported from one place to another through digital messaging and storing files within flash drives. Moreover, and one of the most important aspects of CAD, is the ability to analyze a design from various angles with a lot of ease and being able to see exactly how a product is going to look after it has been manufactured, unlike drawings which cannot accurately convey the overall product. In consequence, all of which was stated assists designers in optimizing a design to perfectly fit any product requirement.

Figure 1- Computer capable of running CAD

With that being said, a CAD computer is any conventional computer that has the required specification in order to actually run CAD-based applications, which entails that the overall strength and ability of said computer has to be relatively strong since – as stated earlier – a CAD program allows designers to add a significant amount of intricate details, meaning a computer running said application would be processing a lot of information at once due to the process-intensive nature of CAD applications.. Accordingly, this means that a CAD computer needs to have the sufficient processing power and speed in order to for it to prevent CAD application from crashing especially when under a lot of processing pressure. However, in addition to that, the specifications of the computer need to also be high enough for them to prevent crashing in addition to running CAD applications smoothly, as to have said applications constantly lagging would nullify the convenience of using them, and as such it not only needs to run process-intensive applications, but it needs to run them smoothly.

Dedicated applications:

Introduction: *Although a CAD computer can be utilized in the same way that any other personal computer could, said computers are mainly utilized for process-intensive tasks, and as such, only said tasks are going to be discussed. In the following section.*

3D modeling and rendering: *One of the main uses of a CAD computer is as the name mentions, designing, as designing component could – as stated earlier – lead to many intricate and tiny parts, and therefore leading the computer needing to process a lot of components and sides at once, therefore leading a process intensive-operation*

that would be ideal for a strong computer. However, in addition to that, rendering physical simulations created through 3D models also requires a significant amount of processing ability, as in this case the computer not only needs to process the shape of the object, but also potentially render fluid movement and how light bounces of an object, which includes a series of calculations that have to be done simultaneously and in a rapid manner, all of which requiring additional processing power, therefore being an ideal application for a CAD computer.

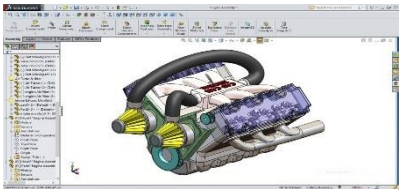


Figure 2- 3D modeling

Video editing and rendering: *Although video editing might not sound process intensive at first, it is in fact one the main applications that a strong computer – such as a CAD computer – would be utilized for. That is the case since editing videos requires for the computer to be able to decode large files that can range up to tens of gigabytes worth of video at extreme speeds, which is the process of taking compressed files that are given in a format that is understood by the computer only such as mp4, mkv, wvm, etc., and turn them into the raw video format that is understood by humans, which – in the case of a video editing software – is done in real time in order for the editor to be able to actually see what they are working on as they are editing it. The intensity of such process is amplified further depending on the quality of the video as better quality means more pixels per frame of a video is comprised of which means more larger files and therefore a larger amount of data to be decoded in real time.*

Data science and analysis: *Just like the other applications mentioned, data science and analysis requires for the computer to work with a massive number of data and huge databases, and depending on the exact way that said data is going to be utilized, the required processing power would increase significantly, in that if it were to be used for calculations purposes or any operation, which is even amplified more when the data being worked on is the accumulation of years' worth of business-related data, which is the main area that data analysts generally work in, as such, another ideal usage for a CAD computer is for data analysis purposes due to the strong processing power that would be required in order to do it efficiently without causing the application running a given algorithm to crash.*

Video game development: *Another major area in which high processing powers are required is in the video game development fields, in that – just like 3D modeling – a video works with a lot of intricate details and models that have to be rendered in real time especially in three dimensional video games while in addition also taking into account player movement throughout the game, all of which in addition to any other calculations that the game has to do such as calculating suspension physics and aerodynamics within racing games or rendering oceans and working with fluid dynamics in games that include such a feature. All of which combines to make a process-intensive application that would be well suited relative to the specifications of a CAD computer.*

CNC controllers:

Definition:

A CNC machine – or Computer Numerical Control – is an industrial grade manufacturing machine utilized in shaping various types of materials from metals, ceramics, composites, woods, and plastic through the use of subtractive manufacturing process, a process in which the machine starts with a solid block of material that is bigger than the required shape and dimension, and is then shaved down through the use of different cutters and tools until the exact dimensions are achieved. However, the main aspect of a CNC machine is that the entire process is done automatically, hence the name, in that a computer controls the different arms and tools that the machine possesses through the use of a numerical process that dictates how said tools should move. Although the main function of a CNC is to shape material, the way in which this process is done could differ drastically from one CNC machine to another, with CNC machine types ranging from CNC mills, lathes, grinders, drillers, CNC plasma cutters, CNC electrical

discharge machines, and more, however, one thing that is in command between all of them is the utilization of a CNC controller.

Now, a CNC controller – the computer system to be discussed – can be considered as the "brain" of a CNC machine, as it is the computer system that controls any operation that the machine would have to do from the positioning of machine components and the speed at which they are rotated, which is being done through the use of programming languages known as "G-code and M-code", which are then decoded by the CNC controller which in turn turns them into actual signals that the machine's motors understand and as a consequence initiates mechanical operations, all of which would be discussed in further detail throughout the following sections.

Figure 3 - CNC controllers

Applications:

Running any numerically controlled machine:

A CNC controller's main purpose is to convert digital files and commands such as G-code and M-code into actual mechanical movements, and with that basic concept alone, it can be utilized for running any numerically controlled machine such as traditional metalworking CNC machines, laser cutter and engravers, and even 3D printers. Although a single machine cannot be utilized for all of the stated purposes to requirement differences in the body of the stated machine, a CNC controller can nonetheless be utilized to run any of them. Although a CNC controller does not technically have any other application, the machines it is utilized in are generally used in three distinct areas which are the following:

Precision manufacturing: *One of the biggest areas in which CNC controllers and CNC manufacturing are utilized is within industries that require precision manufacturing such as the medical, aerospace, automotive, and the arms industry. All of which share a common requirement for precision manufacturing and very tight tolerances in order to be able to achieve their purposes adequately, in that any imprecisions during the manufacturing process could potentially lead malfunction later on during the life cycle of the product which consequently risk their user's health and safety. The reason CNC controllers and machines are utilized for such purposes is due to CNC controllers being algorithmically controlled leads to them having very accurate and calculated movements, which as a result leads to CNC machines being able to achieve tolerances as tight as +-0.127mm according to* (Velling, 2020).

Niche manufacturing: *One of the main areas in which CNC controllers and CNC machines in general are utilized is in Niche manufacturing, which are any manufacturing processes that are for very specific components or items that are usually manufactured in low volumes that are generally under the 100-piece mark. This is the case due to the relatively low lead-time and capital expenditures required for utilizing a CNC machine in comparison to other manufacturing processes such as forging, powder metallurgy, and casting, all of which a significant sum of money for the and weeks or even months for the preparation of the necessary equipment and molds. However, in the case of CNC machines, it is usually a matter of hours to make sure that all aspects of the machine are set correctly, and from there the subsequent process generally relates to downloading the required files and running the CNC machine, whether that is a metalworking machine or a 3D printer.*

This is also why CNC machines are very popular for model prototyping since prototyping processes generally have the same volume requirements as Niche manufacturing and therefore making it the ideal manufacturing process for the required job.

Hardware

What is hardware:

Definition:

Hardware refers to any tangible physical components available on a computer, said components are connected together and provide the computer with its most basic functions. Hardware components are split into two categories, external and internal component, both of which are going to be discussed in the following section. Additionally, hardware components are classified into two parts, peripheral and non-peripheral, peripheral devices are devise that connect to the main computer and are not an integral part of the actual computer system, while non-peripheral devices are ones that are utilized for running the system itself, in that without them the computer would not function at all.

External components:

Definition: *External components are parts of a computer system that can be seen from outside of the system's enclosure, hence the name. Such components are integral to the core function of a computer system from a user interaction standpoint, in that they are the only means for the user to be able to interact with their computer system. External components can be categorized into two different sections, with them being input and output components. External components can all be referred to as peripheral devices, since although they are necessary for the user to be able to interact with the computer, they are not necessary for the computer to run.*

Input devices: *Input devices are the ones that allow the user to input information into the computer system and actually allow the user to control their computer. Examples of input devices are keyboards, mice, microphones, webcams, scanners, and so on. Such devices allow the user to interact with the computer system through inputting information that can then be utilized by the computer depending on the type of information that is being sent and what device is sending it.*

Output devices: *Output devices are devices that allow the computer to interact and transmit information to the user that has been initially translated from language that the computer understands to one that humans can easily comprehend. Examples of output devices could include the monitor, speakers, headphones, printers, projectors, and more. Without output devices, the computer has no way for transmitting or "outputting" data to the real world for humans to make use of.*

Internal components:

Definition: *Internal components are the opposite to that of external ones, in that they are the devices that cannot be seen from the outside of the computer system's enclosure, but rather the user would have to open said enclosure in order to access the internal components. Most internal components are components that have a core function and responsibility in the overall operation of the computer system, and without them, the computer system would not work as intended, making them non-peripheral component, however, there are nonetheless certain peripheral internal component. A computer's internal system is not only made up from the internal components themselves that are used to provide the computer's different function, but an equally important part is the architecture through which said components are connected together and organized.*

Computer architecture: *As stated, computer architecture related to the system of connection that allow the different internal components to interact with each other. The architecture system consists of conductive electrical lines placed that go into and out of each component. Said lines are placed parallel to each other and allow for electrical signals to be sent from one component to the other which is*

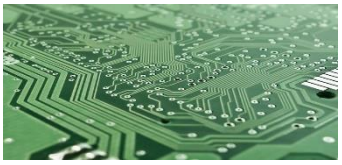


Figure 4 - Computer architecture

the method in which computer component interact with each other. Each line placed in the mention parallel formation is equivalent to a single bit as each line is able to transfer that amount of data each time it sends a signal, a process that is done in an extremely rapid pace. Moreover, a group of these lines that are utilized for a given purpose are generally known as a "Bus".

CAD computers:

Internal components of CAD computers:

The components:

Motherboard: *The motherboard is the main Printed Circuit Board (PCB) that is utilized by the system, meaning it is the base utilized in which the system's components are connected to each other, as such, the motherboard is considered to be the main component of the entire system due to it being responsible for allowing components within the system to actually interact with one another which is made possible through the aforementioned computer architecture that are available on the motherboard. In addition to connecting the system's integral components, the motherboard has additional empty slots that allow for the addition of any peripheral components that might either enhance the system or provide it with a new function such as additional sound card, external hard drives, and RAM slots.*

Figure 5 - The motherboard

Additionally, most modern motherboards nowadays also include both a Network Interface Card (NIC) and Sound board integrated into them, with the sound card translating audio from digital data such as mp3 into audio that can actually be heard, while the NICs provide connectivity to the internet via either wireless communication through the use of radio waves or wires through ethernet cables, said NICs send signals in binary form into routers, additionally, NICs contain a unique code known as the MAC address which is used in order for routers to identify the sender. The two aforementioned devices do not play a key role in a CAD computer's overall system and as such they were explained briefly here.

CPU: *The CPU, standing for Central Processing Unit, is considered to be the "brain" of the system, due to any functions that the computer has to do such as the transfer of data through the computer architecture, calculations, commands, encoding and decoding, interpreting input signals from external devices, and more have initially go through the CPU, as it is the component that actually transmits the instruction to other components via the use of electrical signals and the computer architecture. Although certain components are able to perform their function without the CPU, the CPU does inform said component about time in which they should operate and the duration.*

Figure 6 - The CPU

The calculations being done by the CPU are done via a circuit found within the component known as the Arithmetic Logic Unit (ALU), also known as the CPU's core, this circuit allows the CPU to perform it main function as it gives the CPU the capability of adding and subtracting as well as basic arithmetic and logic functions which are responsible for translating binary into understandable data, the core with binary being the main method in which components and computer systems in general communicate with.

in general, a CPU would have multiple cores/ACUs that generally range from 2 to 8 cores, which simply assist in increasing the processing speed of the CPU, with said cores working only when needed, in that a CPU could turn off one of its cores if it is not in use. With that being said, the CPU as a component itself is unable to transmit those

signals on its own, but rather has to be controlled via a piece of software known as an operating system which would be discussed in further detail later throughout the report.

Due to the process intensive nature of CAD, the appropriate CPU to be utilized for running said application would be to use any CPU with a minimum of 4 cores for basic development and designs and a recommended amount of 8 cores for more intricate designs as well as 3D rendering. Additionally, the overall clock speed of the CPU is recommended to be around 3.5Mhz to allow for great processing speed which would be required especially during rendering as mentioned by (InfraTech, 2019).

Cooling component (heatsink and fan): *During a CPUs operation, electrical current passes through it constantly and rapidly, however, a portion of the electrical energy passing through the CPU is lost and transferred into other forms of energy with the most prominent being heat energy. Due to this, a CPU could potentially reach temperature upwards of 100 degrees Celsius, which can cause long-term damage to the CPU and potentially burn it. As such, a cooling component is generally utilized in order to cool it down, although said components can vary, with the most popular being utilizing a heatsink-fan combination or water-cooling the CPU, however, the one most commonly seen in conventional as well as CAD computers is the heatsink-fan method, and as such it is the one that is going to be discussed.*


Figure 7 - Heatsink and fan

A heatsink is a component that consists of a base with a large number of fins extending from it with the material being utilized for it being either copper or aluminum due to their great thermal conductivity, additionally, the heatsink is generally designed to have a relatively large surface area in comparison to that of the CPU. When the heatsink is used in combination with a fan in order to cool down the CPU. The method in which this process works is that the heatsink is placed over the CPU which results in heat being conducted from the CPU onto the base of the heatsink, from there, the heat is dispersed onto the fins, as that is happening, the fan disperses heat further by generating air that carries the heat through forced convection. It should also be mentioned that that a paste consisting of a thermal filler that enhances thermal conductivity.

Graphics card: *A Graphics card is a printed circuit board that plugs into the motherboard, with its main purpose being to output images onto the computer's monitor. The graphics card consists of four majors aspects, with them being the GPU, VRM, VRAM, and the cooling. The GPU, or Graphics Processing Unit, is the "brain" of the graphics card, the GPU is similar to that of a CPU in that they are both small processing chips – with both even being comparable in terms of size – that receive and output information with their main purpose being to perform calculations through the use of cores, however – as stated by* (StikeTech, 2017) *– unlike a CPU, the calculations that a GPU has to make are relatively simple due to the calculations that are done being predictable and are a matter of repetitive mathematics in order to calculate geometrical shapes and any additional features such as fluid motion or shadow alignment, which are much simpler in comparison to the wide range of jobs that the CPU has to do, as such, a GPU could potentially have hundreds or even thousands of cores.*

Figure 8 - The GPU

In addition to the GPU, a graphics card also contains a number of Voltage Regulator Modules that are commonly known as VRMs, said voltage regulators are simply there to ensure that the voltage going into the GPU is consisted and below the maximum appropriate amount. Another crucial part seen within the graphics card is the VRAM, also known as the Video Random Access Memory, which acts just like a normal RAM would except it is dedicated for storing graphical data and images that are sent to it through by GPU, in addition to storing information, the GPU also reads information from a section of the VRAM known as a frame buffer, said frame buffer – in accordance to (Videocide, 2020) *– contains a file known as a bitmap which is a type of file that tells the GPU the location and color*

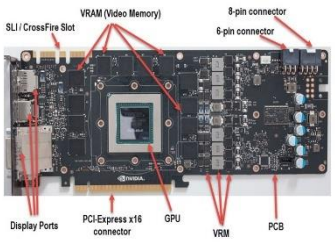


Figure 9 - GPU's internal components

of each pixel to be displayed on the screen, using it, the system can store a larger amount of rendered objects on the screen, meaning a larger amount of VRAM leads to being able to display more objects on the screen at a time without the screen having to buffer. After the entire image has been rendered, it is then sent to the monitor via a cable connecting it directly to the GPU. Finally, just like the CPU, the GPU needs a cooling system in order to keep its temperature below the operating limit, as such, the majority of the graphics card is specifically made for that purpose, with the main structure and body being composed of a heatsink while also including a fan that is integrated into the graphics card.

However, as mentioned by (Tyson, 2021)*, any information that the GPU renders and displays onto the screen has to initially be sent to it via the CPU. It should also be noted that although a GPU's main application is to display and render images, it could also be utilized for a GPU can be used for other applications, said GPUs are also known as GPGPUs, or General-Purpose Graphics Processing Unit.*

In terms of the GPU that would be used for CAD development, it would be recommended to have a minimum of 4 gigabytes of VRAM for mid-range rendering, and around 8 gigabytes for more intensive and intricate renders and designs. Moreover, as shown by (InfraTech, 2019)*, a recommended GPU clock rate would be something around 3.5GHz.*


Figure 10 - The RAM

RAM: *The Random Access Memory, abbreviated as RAM, is one of the most crucial parts of the computer system, it is a form of temporary memory that allows that CPU to read, write, and delete information from while the computer is running, and as soon as the computer stops operating, all data from the RAM is deleted. The type of information stored onto the RAM is anything that has to be constantly used by the CPU in order to keep a given piece of software running, with such information ranging from anything such as the necessary information used in running the actual operating system of the computer or any data that any running software applications might need to be stored, including any files CAD files that are running on the computer. Each space within the RAM Is known as an address, meaning that whenever a CPU needs to utilize some information that it has stored, it first takes said information from the RAM address that it has initially been stored in and then uses it as deemed needed. The data that is being taken from the RAM can be taken from any given address at any given time, hence the "random" seen within the name, in that data location within the RAM is done immediately rather in a sequential format in which the system checks each address.*

The RAM is one of the most crucial requirements of CAD applications due to the large amount of data that needs to be fetched simultaneously during intricate and intensive 3D development, as such, a large memory would in turn be needed. According to (InfraTech, 2019)*, the minimum amount of RAM required for mid-range to intricate 3D CAD development would be around 16 gigabytes, with 32 gigabytes being reliable and more than adequate. To put this into comparison, a general-purpose computer would need somewhere between 4 gigabytes for daily use and 8 if semi-intensive applications were to be needed.*


Figure 11 - The ROM

ROM: *The ROM (or Read Only Memory) chip of a computer is the cache in which the manufacturer installs the basic launch commands that the computer requires. Said component is build into the motherboard, and – as the name suggests – unlike the RAM, the ROM chip can only be read from and cannot be edited by the user as it is fully programmed by the manufacturer during production and has been intentionally made so that its access is restricted. The ROM mainly constitutes of boot-up instruction that are required for the PC to initially run, this is especially useful when no operating system has yet been installed into the system, as the ROM would still be able to provide a very basic user-interface that has the bare minimum, with said interface being known as the BIOS. With that being said, the ROM still has other major functions which can be accessed through the stated BIOS menu such as detecting certain hardware flaws within the*

system and relaying them onto the user as well as controlling settings of some of the hardware components and the bootup order of the system.

Permanent storage (HDD/SSD): *There are two major forms or methods in which non-volatile memory (memory that does not automatically get erased when a computer is turned off) can be stored. The oldest of which is known as an HDD, or a Hard Disk Drive, according to* (Senanan, 2015)*, an HDD consists of an actuator arm held above rotating disks that have been coated using microscopic magnetic grains, with a group of said grains consisting of a single bit. The magnetic force of said grains is set to face a given direction that can either correspond to a binary value of zero or one. Whenever something is written onto the hard drive, binary values are sent to the actuator arm, which in turn turns those values into electrical signals through the use of an electromagnet, the electrical field created by the electromagnet has the ability to switch the direction of the magnetic force on the coated magnetic grains seen on the disks, and due to said direction determining the binary value, the change in direction changes the value that they holds, therefore making the writing process possible. On the other hand, in order to read the values from the magnetic grains, a magnetic reader is used by the hard disk drive in order to read the direction of the grains, and consequently turns them into electrical signals that are then sent back to the computer.*

Figure 12 - An HDD

The other type of permanent storage the Solid-State Drive, abbreviated as SSD, works by utilizing a type of memory technology known as flash memory. This type of memory works by using a component known as an FGMOS, or a Floating Gate Metal Oxide Semiconductor, a component consisting of three electrical nodes, the source and drain which correlate to the input and output respectively, and a gate node, which is connecting to a "Floating gate" which is storing compartment that allows for the storage of electrons. As mentioned by (BLITZ, 2020)*, the way this process works is that whenever the floating gate is empty, electrical current can pass through the source to the drain, and therefore provide an electrical signal that correlates to a binary value of one. However, if the floating gate were to contain electrons, then the voltage required to pass through the channel connecting the source and drain is higher than the voltage supplied to them, therefore a signal cannot be sent, and as such a value of zero would be received. The number of the stated floating gates that an FGMOS holds related to the number of binary values that it can hold, in that if an FGMOS had 16 floating gates, and none of them had electrons, that would be a binary value of 1111 as the entirety of the current can pass through, while if all of them had electrons, then it would be 0000 since the voltage required to pass through the channel would be very high, and therefore no current would pass, with other levels of stored electrons in between being full and being empty such as having 9 out of 16 floating gates as full relating to alternative binary values that are in between 0000 and 1111. All this means that in order to write binary values into these gates, electrons would have to either be either added or removed from the floating gates, to add electrons and decreasing the binary value, a voltage would be supplied to the gate node, while to remove electrons and increase the binary value, a given voltage would have to be applied to the source and drain terminals.*

Figure 13 - An SSD

Between the two methods used for permanent storage, an SSD is much faster and more reliable due to it not needing any moving parts, meaning that there is less chance for it to break and it is not slowed down by mechanical and physical limitations. As such, between the two, an SSD would most definitely be preferred for a CAD computer over HDDs as using an HDD would lead to much slower run times and slower file transfer especially when large models with relatively large file sizes are being transferred.

PCU: *Before any part of the CAD computer system works, power needs to be distributed into its components, which is done through the use of a PCU, or Power Supply Unit. Power for an computer is generally supplied through the use of an electrical socket which provides a voltage of around 240 volts, which is much more than what is required for the component, and drawing in such an amount of voltage into the system would cause it to short-circuit, additionally, the power supplied from wall sockets comes in the form of alternating current, while power going into*

a computer needs to be in the form of direct current as it is easier to control and more consistent in supplying power. As such, a PCU is utilized, in which, a transformer decreases the supplied voltage from the given 240 volts to what is required by the computer using two set of coils, one of which taking in the 240 volts, which creates a magnetic field that causes electricity to form in the second coil, however, the second coil is winded less than that of the first one, and therefore produces less voltage than the first one, therefore decreasing the voltage. After the voltage has been decreased, power then goes a bridge rectifier that turns AC to fluctuating DC, power then goes through a capacitor that takes in and outputs a voltage in a rapid manner so that a ripple voltage is created, finally, a Zener diode is employed to filter out the ripple voltage and turn into a straight direct current, which can sufficiently be used by the computer.

Figure 14 - The PCU

Computer architecture:

Types of busses in CAD computers: *In a CAD computer, busses are the main form of communication for the CPU with the rest of the component and there are two methods in which this connection is established, the first of which is in a unidirectional method, which is where the data is only being transferred from the CPU to a given component, with the other method being bidirectional, in that data gets transferred both from the CPU to the component and from the component to the CPU itself, meaning data goes both ways, hence bidirectional.*

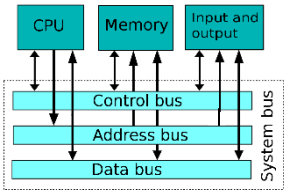


Figure 15 - The system bus

Address bus: *The address bus is a unidirectional bus that connects the CPU to the RAM. The CPU uses this bus in order to locate and identify an available address on the memory. This process is done in order for the CPU to know what address its going read from or store new information in. The greater the number of bits (the width/number of lines) that the address bus, the greater the number of addresses that the CPU can locate at once, therefore speeding up the process of locating free memory/addresses available in the RAM. Additionally, the address bus could be used by the CPU to identify an available input/output device which is also done in a unidirectional manner.*

Data bus: *The data bus is bidirectional and it purpose is to allow for the CPU to carry data to other components such as data to be stored into the RAM, or rendered files to be sent to the output devices. However, due to the data bus being bidirectional, it also allows for data to be carried from other components like the RAM or input devices into the CPU. It should also be noted that the data carried by the data bus is in the form of binary.*

Control bus: *The control bus is another type of bidirectional busses utilized by the CPU. Its main task is to send commands from the CPU to other components and controls the actual timing for when certain components are to operate. This is not to be confused with the data bus, which transfers data, in that the control bus transferred HIGH and LOW electrical signals known as clock pulses which tell the other components when to run and not, while data refers to the transfer of binary signals. Moreover, the stated operation is done so in an organized and sequential manner as to avoid data collision, which is when multiple signals are trying to be sent causing one of them to interfere with the operation of the other.*

The aforementioned operation was the control bus's job as it is transferring signals from the CPU, however, as it is sending them to the CPU, its purpose is to carry status messages from other devices to the CPU, with said status messages containing messages that could force CPU to task the RAM with backing up its memory or for the CPU to prioritize a given command over the other such as prioritizing a mouse click over a loading an application.

DMA: *Direct Access Memory (abbreviated as DMA), is a method employed in computer architecture that allows certain devices to directly access the memory by going through a dedicated bus rather than having to initially go through the CPU. This process allows for memory sensitive devices to quickly access the RAM, making their operations faster and safer. Examples of such devices are the disk drive, graphics card, network card, sound card, and other peripheral devices.*

External components of CAD computers:

Input:

Mouse: *The mouse mainly consists of two functions, whenever the user wants to click and also it is used in detecting hand movements and translating them into electrical signals that determine the movement and position of the mouse on the screen. The first of which is simply done by transmitting signals whenever the mouse if clicked through a pushbutton. The second stated process is mainly done through the use of an LED that emits light from the bottom of the mouse onto the surface, said light is then reflected by the surfaces and bounces back, from there it is captured by a photodetector that detects the reflected light. According to (JLW, 2017), the photodetector – which generally is made up of a CMOS transistor – then forms thousand of images every second from the light signals that are then sent to a digital signal processer which compares the images being sent to it and determines whether or not the mouse moved and at what rate. The aforementioned process can also be done through the use of a mechanical ball that transmits signals of the direction of its rotation to the computer, which determines movement, however, this technology is considered to be inefficient and has been obsolete for a while now.*

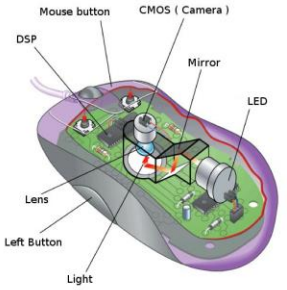


Figure 16 - The mouse

Keyboard: *The way a traditional keyboard works is that its PCB consists of a rows of open circuits – open in that current does not flow through them – that are connected to a microprocessor, whenever a button is clicked a single rubber-like membrane sheet that is under all keys is down and closes the circuit from the position of the clicked key, and a small of current is able to flow through the microprocessor, which contains a keymap for each individual key. Using said keymap, the microprocessor what value each button represents, using that, the microprocessor translates the signal into binary, which is then sent into the computer. The aforementioned function is that of a membrane keyboard, another type, called the mechanical keyboard is also utilized, with the difference between the two is that in a mechanical keyboard a switch is actually placed under each key which directly sends a signal to the microprocessor. Mechanical keyboards are generally known to be faster, and more durable, however, they are also more expensive.*

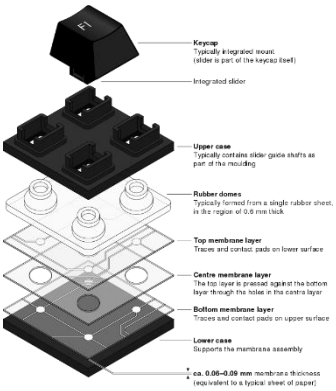


Figure 17 - Layers of a membrane keyboard

Microphone: *Whenever someone speaks into a microphone, transmitted soundwaves hit a rubber membrane known as the diaphragm which have electrical coils wrapped around it, additionally, surrounding the diaphragm is a set of magnets. Due to the soundwaves, the diaphragm moves downwards causing the coil to move through the magnet, and therefore cause an electrical current due to electromagnetism. Said electrical current is used as an electrical signal that is sent to the computer in the form of binary. This is then decoded by the machine and consequently transforms it into audible noise.*

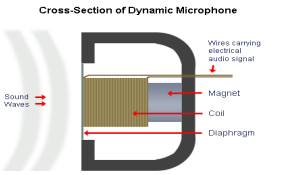


Figure 18 - Microphone illustration

Output:

Monitor: *As of today, there are two major types of monitors utilized worldwide, with them being LCD and LED screens, however, LCD screens are the ones mostly used worldwide, and as such they are the one that are going to be focused on. An LCD screen, or Liquid Crystal Display, the way said display works is that a layer of a material known as liquid crystalline is placed in front of the screen, said material has unique properties that allow it to shift and change color based on both light and electrical fields and currents, the LCD setup works by having a white light shine from the back of the screen, from there, the LCD screen is placed in front of it with two transparent electrodes being in front of it and behind it, and in front of all of what was mentioned is either a red, green, or blue filter, with this*

setup being done for each pixel seen on the screen. The process goes as follows, white light passes from the back of the screen, goes through the liquid crystal and onto the filter, which – depending on the color of the filter – output that color (i.e: if the filter was green, then a green color would be displayed). However, the intensity of the color had to be decreased, voltage would be sent to the electrodes, causing the crystalline structure of the liquid crystal to shift, and in consequence decrease the intensity of the light going through the filter. The combination of all three red, green, and blue filters while having the ability to change their intensity allows for the creation of any possible color, in that if a green intensity of value 255 red, 40 green, and 150 blue would provide a color close to that of a dark purple. The computer's function within the stated process is providing the required amount of voltage for each electrode in each pixel to provide the required color for each red, green, blue pixel combination.

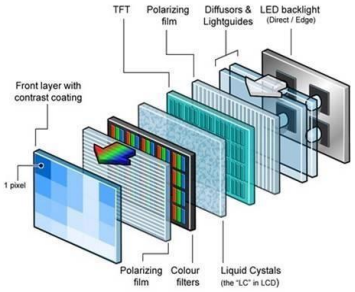


Figure 19 - LCD screen working principle

Speakers: *A speaker words along the same principles that a microphone works except it does so the other way around, in that within a speaker, a conductive coil is wrapped around a tube, which is placed over a positive magnetic and is surrounded by negative magnets on the right and left or vice versa. Using this, the computer sends an electrical current to the coil, causing a magnetic field that pushed the tube forward, this in turn pushes a cone placed over the tube, which – as it interacts with air particles – produces sound waves that are pushed forward for the user to hear.*

CNC controller:

Internal components of CNC controllers:

PCU: *The working principles of a PCU found within a CNC controller are the same as the ones found in any other computer, as such, the PCU section would not be repeated here as to avoid repetitiveness.*

PLC/MCU:

Within a CNC controller is a dedicated Programmable Logic Controller (PLC) known as the Machine Control Unit (MCU). In general, a programmable logic controller is a computer that can be easily programmed in order to perform logic functions and mathematical operations that are used in controlling input and output functions of varying hardware components such as motors, lights, sensors, and so on, essentially a PLC can be considered as a scaled-up microcontroller utilized for industrial applications. With that being said, an MCU is a PLC that has been purposefully built for controlling CNC machines as its software has been dedicated for the use of programming languages utilized by CNC machines (G-code and M-code, more on them in the software section) as well as having dedicated peripheral devices that are used by the CNC machine.

The MCU itself can also be additionally separated into its own components; such components are going to be explained in the following section:

DPU: *The DPU, also known as the Data Processing Unit, can be considered as the "CPU of a CNC controller". As mentioned by* (Sathyabama University, 2022)*, the DPU's purpose is solely for calculation purposes and acts as an algorithmic calculator for the CNC controller and is also used to decode g-code into binary values that are then sent to the CLU to work with. The DPU also consists of an input device such as a tape reader that is used to actually read the g-code. Additionally, the DPU is used for interpolation, which is used to smoothen out driver movements by calculating optimal movements between two positions provided in the data that is read from the g-code.*

The reason why a CNC controller utilizes a DPU instead of a CPU is simply due to a CPU being unnecessary in an operation that would be used entirely for calculations and data processing's sake, rather than general purpose computing, which is what the CPU mainly specializes in.

CLU: *The CLU is the component responsible for sending the decoded binary data to the motor drivers of the CNC machine which in turn are used to control the motors. Meaning the CLU's job is to control the executive programs that control the velocity and on/off operations of the motors and the machine tools that said motors operate.*

I/O pins: *The IO pins (input/output) that found within an MCU are simply the pins utilized for inputting and outputting electrical current or signals. Input pins are generally utilized for sensors and the actual user input, while output pins would be the pins going from the CLU to the driver motors or any other output device. Said pins can also come in both analogue, and digital forms, with analogue being signals that have a given range, while digital signals being either HIGH or LOW, and cannot have values between a given range such as zero to 100 volts. It should also be noted that input and output pins are likely to employ Analog to Digital as well as Digital to Analog Converters (ADC and DAC) in order to input signals given in analog form to a digital format, or vice versa, in that the data given to analog output pins is initially in digital binary format, and is then turned into analog signals that then transmitted into the motors.*

RAM: *Just like the RAM in a CAD computer, the RAM within a CNC controller is used for the storage of data that is going to be continuously read from and extracted by the CPU and is considered to be volatile, in that when the computer system controlling it shuts down, any memory found within it is permanently deleted. Within a CNC controller, the type of data stored within the RAM is – according to* (Rao, 2022) *– the g-code as it is constantly being read from by the DPU in order to decode it and provide positional commands to the CLU and in turn the motor drivers.*

The RAM used by the CNC machine can vary from around 8mB to potentially 1GB, the reason to that the memory space a CNC machine uses is extremely little relative to that of a Cad computer is that the main thing that the CNC controller stores within its RAM is g-code, which is simply written code placed within a text file format. Said format requires very little space, with even text files ranging into the thousands of lines of written code not even reaching 10 mB, and so the need for memory space comparable to that of a CAD computer is very excessive.

ROM: *The ROM seen within CNC controllers is similar to that of the one within CAD controllers, in that it stores non-volatile memory that is set by the manufacturer. As mentioned by* (Rao, 2022)*, the ROM is utilized for storing executable commands such as the ones used for turning on or off certain components such as loading the coolant or turning on a given motor, with said commands being the ones controlled by the M-code.*

Permanent storage: *Unlike the CAD computer, a CNC machine does not require any permanent storage, that is the case since any application that are needed during bootup are already embedded within the CNC system of choice (more on this in the software section), meaning that they are not stored in a dedicated area such as an HDD or SSD. On the other hand, the user might need certain applications to be permanently saved in the computer system in order to launch or run the following time the computer is turned on.*

Circuitry Protection System: *According to* (Jacobs, 2021)*, the Circuit Protection System – generally called CPS – comes right after the MCU. The CPS consists of a breakout board that is used for taking in signals from the MCU, separating them so that each motor driver gets the signals it requires, with said signals then being transmitted to said drivers using the CPS. In addition to the isolation and transfer of electrical signals, the CPS additionally provides an easy method to connect peripheral devices such as the drivers, as dedicated slots would be available on the breakout board for such purpose. Finally, the CPS is also used as a safety measure between the MCU and motor drivers as it has fuses that would blow up and prevent the flow of electricity in the case of an electrical surge, which in turn protects the motor drivers and therefore also protects the product being machined as well as the health and safety of the machine operators.*

Motor drivers: *The signals taken in by the CPS are then sent to the motor drivers, which are used in order to actually transmit the required pulses for the stepper or servo motors that would be controlling the CNC machine's tools. Said pulses command the motors with the position and rotation/movement velocities of the motors. As mentioned by* (CNC Router Source, 2011)*, the overall operation of the drivers can be done in either two ways, an open loop or a closed loop. Within an open loop system, the drivers simply receive the signals and command the motors to work, without checking whether or not said motors have done their jobs, however, in a closed loop system, a feedback loop is added to the overall operation of the CNC machine, in which, sensors such as a limit switch or temperature sensors are added to make sure that the operation is working as intended, and if not, the signals received by the drivers change accordingly to fix the issue, this process works in hand with the MCU as it is the system that receives the feedback from the sensors and edits the information being transmitted to the drivers.*

External components of CNC controllers:

Display unit: *The display unit or monitor found within CNC controllers uses the same LCD or LED technologies found within any other monitors, as such, explanation of said topic would not be repeated to avoid receptiveness. With that being said, the type of information displayed on these monitors usually consists of commands that the machine is currently running, feedback from the attached sensors, machining progress, and other useful information that a CNC machinist/operator might find useful.*

Keyboard/buttons/switches: *In addition to the display unit, the outer casing of the CNC controller contains a keyboard, buttons, and a set of switches, all of which works via the same way explained earlier, which is by pushing a wire down to complete an electrical circuit that was initially opened. Said buttons can be used for a variety of different jobs, with them differing based on the specific CNC controller being used.*

Sensors: *Sensors utilized by CNC machines can drastically vary from one machine to another, however, some of the more essential sensors include linear transducers which provide the motor's current position by calculating the displacement and converting it to binary values that are relayed to the computer. An accelerometer which calculate the overall speed and acceleration of the motors. And finally, a temperature sensor which provides necessary thermal reading used for analysis and evaluation for material thermal properties.*

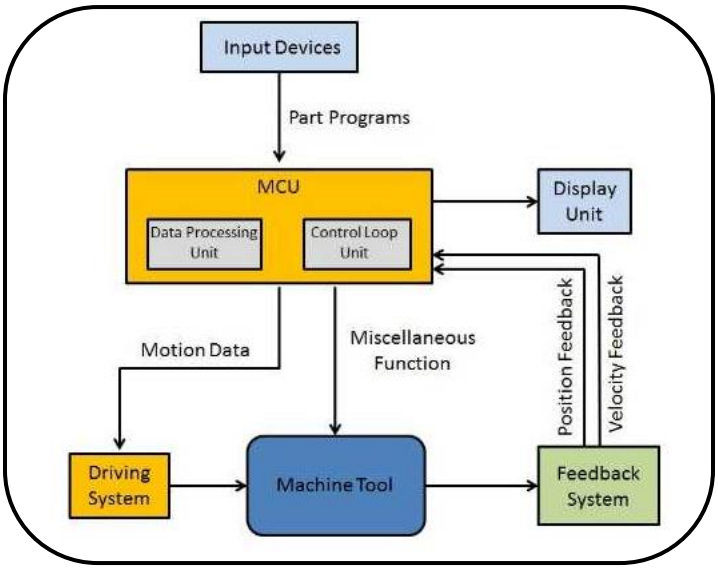


Figure 20 - Working process of a CNC controller

Software

What is software:

Software definition:

By definition, software is the non-tangible aspect of a computer system that is necessary for its overall function. However, for software to function, the data transfer, logarithmic calculations, and operations made by the computer's hardware component are a prerequisite for software to function, which is the case since software at its core is stored, transferred and operated in binary forma. Therefore, software can be considered as the product of the simultaneous operation executed by the computer system's hardware components. With that being said, having hardware component on their own are simply not sufficient for a computer system, and software is what the user actually utilizes the system for. Overall, three distinct types of software are utilized for varying jobs and applications, with said types being system software, utility software, and application software.

Types of software:

System software: *The system software can be defined as the gateway for communication between the user and the computer system's hardware component. That is the case as the main task of the system software is directing and operating the system's core (whether that is the DPU or CPU) while also providing a platform and an interface for the user to be able to input commands and communicate with the system with relative ease.*

Utility software: *Utility software relates to the applications and varying elements and features that the system software employs within the computer system which assist in maintaining said system and allowing it to function and run smoothly while also preventing potential threats to the data found on the system by protecting it from potential harm that could occur to it in any digital form. As such, utility software is usually dedicated and made towards protecting the system from issues at the very low level (i.e. Binary and assembly) rather than being applications that the user can freely interact with.*

Application software: *Application software relates to any app downloaded onto a computer that is meant to assist the user in performing a specific task that the application has been developed for. Application software can be considered to be more user-oriented in comparison to that of utility software, as it designed with the user in mind so that they are able to use it with relative ease and is in general more convenient to use than utility software applications.*

Software in CAD computer:

System software:

System software within CAD computers: *Within CAD computers, the system software consists of any software programs found within the computer that allow for the interaction between the user and the hardware devices, as mentioned by* (JavaTpoint, 2022)*, the system software is responsible for communicating with peripheral devices such as monitors, and printer, moreover, it is tasked with providing configuration files of the system's startup. However, the system software's major tasks resides within providing the operating system that the computer system will run on. The operating system is the actual part of the system software that communicate with the computer's hardware component. That is the case since it is the actual part of a computer system that provides commands and orders to the CPU itself, since although the CPU itself is the component sending those signal, the thing controlling the flow of signals as well as their data is the operating system. Moreover, the operating system*

also acts as a hub in which all application software programs are accessed from. Overall, the number of major tasks that the operating system has to do in order for the system to function can be split into four, with them being memory management, processor management, device management, and file management.

Operating system jobs:

Memory management: *Memory management is the process of allocating space in the main memory of the system (the RAM) for it to be written on, this is done by indicating which memory address is specially going to be targeted for it to be either edited (deleted, written) or read from, which this process being done through the use of the address bus. This is done by saving data in sectors of the memory called "pages", which are a series of tables that indicate information of what a given address actually holds, with said information being things such as the size of the item, page number, the memory address of the page, and the status of the address whether its occupied or free. This assists the operating system in knowing exactly where any piece of data is stored in the RAM's addresses and any details that the piece of data stores in the circumstance that it would have to be used.*

Processor management: *As stated, another job of the operating system is processor management, which can be further sectioned into two jobs, processor scheduling and traffic controlling. Processor scheduling is the operating system's job of timing whenever the CPU receives and starts to process a given set of data as well as the duration that the CPU holds said data until it finishes processing it before it gets transferred to a certain section or component of the computer system. On the other hand, the traffic controller aspect of process management relates to the tracking of the CPUs operations through monitoring its overall status and usage as well as tracking the ongoing status of the current processing operation. Moreover, the actual logic and algorithmic calculations are jobs mostly done by the operating system, which in turn orders CPU with the component or location that requires the processed data.*

Device management: *Device management relates to the operating system managing communication between I/O devices while efficiently allocating said devices whenever they might be required and deallocating them whenever they are not going to be utilized by the user. Moreover, device management also requires from the operating system to monitor the status of the devices connected to the system and understanding their status. Additionally, if a device were to be sent multiple commands at once such as a printer being sent a large number of documents to print, the operating system will queue the commands and the order at which they are being sent, according to* (Tutorials Point (India) Ltd., 2018)*, this is done in accordance to the device's drivers, which are the instruction written by the manufacturer for how the operating system should run a given device.*

File management: *Finally, the file management process is the organization of files into directories that are easy to navigate, file directories being organized structure of file systems that link to related and connecting files within the system. Moreover, the operating system's job is to know the information about the files and data being stores in every given directory including its files and the data they contain, its current status whether or not its accessible and how large it is, and also the location it is in relative to files that lead up to it, with this method of sorting files in the aforementioned method is known as a "file system". Furthermore, the operating system allocates and deallocates information from the files whenever it is deemed necessary or via user input and choice. An overview of the way the file system is organized is as follows (Main directory → Sub directory → Files → data).*

Popular operating systems: *Overall, there are three main operating system that are widely utilized among most computer system, with them being, windows, MacOS, and Linux, (written in order of popularity). Windows is a closed source OS that provides functionalities for everyday use, is easy to navigate, and is the one most utilized around the world. MacOS offers a more professional environment, however, its source is closed even more than that of windows, meaning it is extremely restricted when it comes to customizability and freedom. Finally, Linux is an open-source OS that has multiple variants of it each of which being even considered as their separate OS, with said variants being known as distribution or distros for short. Our of the three, Linux is the least process intensive, and can be freely customized due to it being fully open source, meaning that it could be built specifically for CAD*

purposes. Although in theory Linux might be the best for overall CAD freedom, the overall difference in process consumption is relatively minimal, and the freedom in customization and being able to freely customize Linux to a person's exact needs is not an easy task that requires for the user to know how to utilize the operating system's command line code. As such, there is no single best OS for CAD development, and at the end it simply comes to down to personal preference. It should also be noted that any given operating system would initially have to be installed on the computer system's permanent storage.

Utility software:

Utility software within CAD computers: *Utility software application developed for household and CAD computers are – as stated earlier – application mainly made for protecting the computer system from potential threats to the information and data being stored within the computer. Overall, utility applications can be categorized into three distinct sections, with said categorize being system utilities, storage device management utilities, and file management utilities.*

Types of utility software:

System utilities: *System utilities are the ones installed on the computer system for the purpose of benefiting the operating system directly. The term "system utility" is rather broad and varying applications can be considered as such, however, common applications considered as such would be the ones utilized for the prevention of data access via unauthorized methods and applications used to ensure that the CPU runs smoother and faster. Examples of which could be anti-virus software which scans and prevents deletes potential viruses, Access Control software which provides easy access to given sets of information only to those which area given administrative privileges by the system, and finally, registry cleaners, which scans for data written on the registry that is not being effectively utilized by the CPU, and deletes it from the system to free up space for more data to be allocated.*

Storage device management utilities: *Storage device management utilities refers to utilities that help with anything related to the computer's non-volatile memory. Examples of such utilities could be backup software that transfers an additionally copy of the information into a secure locations as to not lose the data on the system in the events of them being unwillingly deleted. Other examples could be disk scanners which check for any potential physical or logical error found on the memory, disk compressors that save the data into an inaccessible but smaller and more compact format that can then be decompressed to access the information which assists especially when transferring a large sum of data. A final example would be disk defragmenters, which are utilities that separate a given set of data from a file into smaller sections that are split from each other, which assists when saving storage is a major priority.*

File utilities: *At last, file utilities are simply utilities that have any correlation to ensuring the file system is maintained and improved upon. Such utilities could be file clearness, which scan and delete any obsolete or unnecessary files, file encryption software that "scrambles" a given file using a set algorithm so that it is unreadable by conventional file scanners, the process helps in ensuring that if data were to be stolen, the information on it cannot be deduced. Another example would be file/data recovery utilities, which – as stated by* (French, 2020) *– works by utilizing a given set of algorithms to try and reconstruct the data that has been stored based on existing information of the lost data.*

Application software:

Any piece of software developed that does not necessarily focus on managing the computer's hardware and working with the computer from a low-level standpoint can be considered as an application based software. Examples of which could be Microsoft word, excel, teams, discord, steam, any web browser, and so on. However, the two main applications necessary to a CAD computer would be both a CAD and a CAM application (Computer Aided Design/Manufacturing), which are the ones that are going to be discussed.

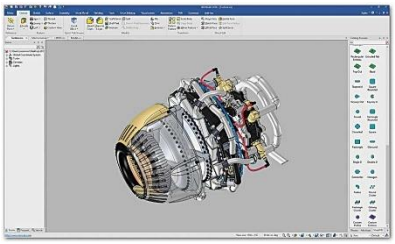


Figure 21 - Modeling example using CAD

CAD: *Computer Aided Design or CAD is the application in which the user is able to create models and designs in either two- or three-dimensional formats. CAD applications work by utilizing objects created by the user using mathematically created and physically feasible geometries. From a software and computer standpoint, two-dimensional CAD applications work by creating linear lines using the linear line formula, with the same process even being utilized for curved lines, and although they are not linear, they created using very small linear lines that are connected to each other in order to form the aforementioned curve. On the other hand, three-dimensional modeling works using a method known as the "polygon mesh method", which works by splitting parts of a bigger 3D model into simpler polygons that can be rendered and calculated separately to form the final model, this allows for the computer to render the final model and then join the polygons together using a given algorithm to ensure that the model does not go outside of physical boundaries, with the polygon utilized for this process usually being a triangle due to its simplicity allowing for models to be calculated and rendered and calculated with relative ease in comparison to other – more complex – models.*

A major example of a CAD application is AutoCAD for two dimensional modeling and Fusion360 for three dimensional. Obviously other applications have been developed for CAD-based uses, however, the aforementioned once are considered to be some of the best currently on the market due to the number of features that they provide which ease the overall modeling process and makes it more convenient. However, a major distinction is ought to be made between CAD applications and general 3D modeling ones such as Blender 3D, in that the difference between the two lies in the fact that CAD software relies on algorithms that heavily rely on mathematical and physical correctness, while on the other hand, software applications such as Blender are considered more artistic and generally lean towards applications related to graphical design as they are not constrained whatsoever by boundaries that ensure that the model being created is in fact feasible.

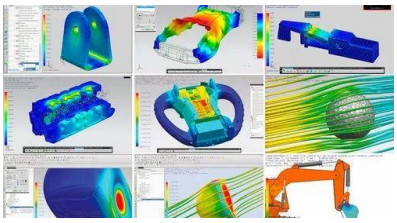


Figure 22 - Varying CAE uses

CAE: *CAE, also known as Computer Aided Engineering or even Computer Aided Simulation, is an application software utilized by engineers in order to ease the optimization and testing process of the design and material of choice for the required product. The CAE software takes an existing CAD file, gives the varying components available on it a material in order to give the component the material's specific properties, and then simulates how the design would work in a real-life context that the user designs, and from said simulation, that CAE application is able to automatically calculate varying material properties and design specifications that would be otherwise extremely difficult, and time consuming to do manually, not to mention the likelihood of inaccuracies due to human error would be relatively high in comparison to the task being automatically done by a computer system. Some of the main variables that the application would be able to provide to engineers would be fluid and air dynamics of the design, the mass and heart transfer, and even the electromagnetic potential, which would be extremely helpful when designing electrical generator components.*

Using CAE, an engineers would be able to easily analyze varying properties of a given part in varying situations and circumstances such as analyzing the aforementioned properties of new design created for the suspension system of a car. Using this, many of the testing processes that would have originally been done in real life are now not needed,

meaning less time and money would have to be consumed on potential redesigns and testing prototypes. Additionally, being able to use a computer software to analyze a given problem would be much easier to analyze in greater depth in comparison to a process working in real life, which might be harder to fully realize compared to having the entire process and simulation in a single screen with all the simulation data being available immediately and in real time as the simulation is playing out in the software. Some popular examples of CAE software applications include Fusion 360, MATLAB, Solidworks, and Solid Edge.

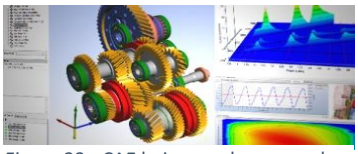


Figure 23 - CAE being used on a gearbox

CAM: *CAM (abbreviation for Computer Aided Manufacturing) specializes in generating the g-code that would be then sent to the CNC machine to follow. The way that CAM applications work is that initially a base plate would be generated which indicates the size of the CNC machine's base, from there a CAD model would be uploaded to the stated base plate. Using this, the application would be able to know both the boundaries of the machine's size as well as the areas it should avoid machining on based on geometries of the product. As such, g-code would be automatically generated to follow the outline of the product, consequently making the CNC machine's tools follow the same outline, and therefore shape the material to the exact specifications of the CAD model. Examples of some of the more popular CAM applications include Mastercam, Fusion 360, and PowerMILL.*

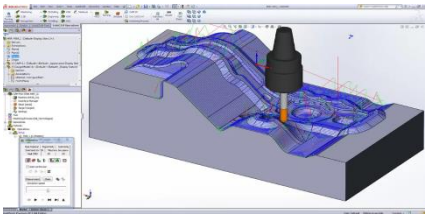


Figure 24 - Generated machine tool path in CAM

Software in CNC controller:

In comparison to CAD computers, CNC controllers are rather limited in their functions, and therefore not many software applications are needed to be developed for the CNC controller's computer system other than the system software which run and control the MCU and the parts within it.

System software:

Unlike CAD computers, the CNC controller's system software is imbedded directly onto the motherboard of the CNC system during the manufacturing process. Overall, there are numerous operating systems available for varying CNC controllers, with that being said – as mentioned in the assignment brief – the systems available for use by the company is the Fanuc and Siemens system, however, they are the two most popular systems currently available on the market, therefore they should offer a wide range of features that any CNC machinist would expect to have. As such, the following section would analyze said systems and determine which would be preferrable based on the application at hand.

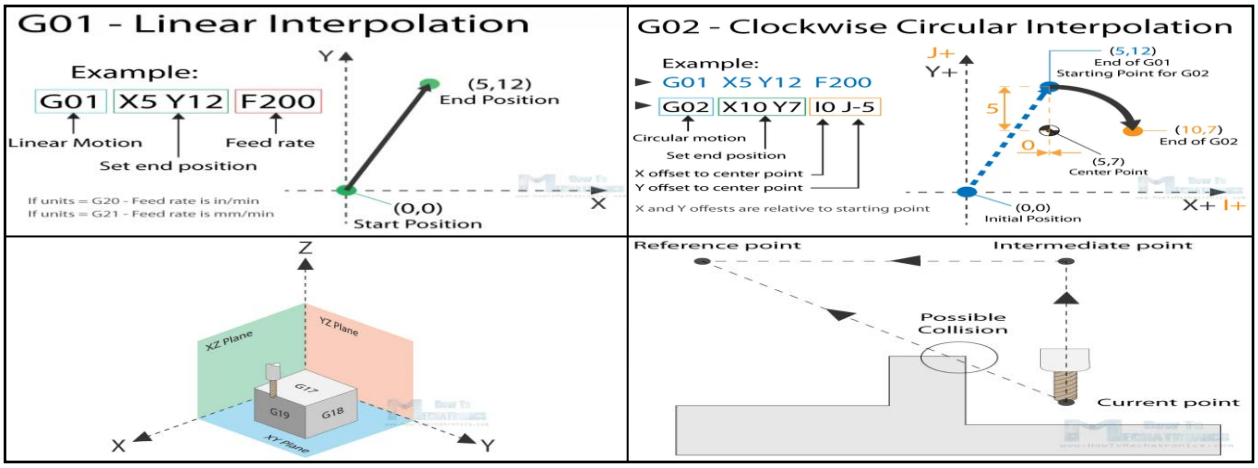
Both of the given systems – Fanuc and Siemens – are very similar in the way that they approach the g-code provided to them and as such there is not difference in terms of compatibility with given CAM applications. Moreover, either systems has been known for working without severe technical issues. With that being said, as mentioned by (S., 2017)*, Siemens systems are generally faster than Fanuc in operation speed however siemens controls are more complicated and harder to learn. Overall, the usage of either system stems from personal preference and localization, in that Fanuc systems are much more common in the American market leading to it also having greater support, however, documentations for Siemens systems are greater than that of Fanuc. However, as mentioned, it mostly comes down to personal preference and the community surrounding the controller system within the country/area that the user is within.*

Machine code:

As has been stated earlier DPU is the part of the system that translates G/M-code into actual operation that the machine does, both of which being mainly provided by the CAM program which automatically generated the code. However, there are certain instances in which G/M-code would have to be manually written or at least understood so that a CNC machinist is able to detect any errors that could potentially occur before they cause a major problem to the piece of metal being machined or the machine itself.

G-Code: *As mentioned earlier, G-code – which stands for geometric code – is the part of the system's program that provides the machine with positioning information. The way the commands are written (the Syntax) for G-code follow a very straightforward pattern of initially providing the name of the command to be executed by writing it as "GXX", where XX equals the number of the required command. After that, most – but not all – commands also require the coordinates in which the machine should move to. Overall, a typical line of G-code would look like the following: G00 X19 Y12. The following are some of the most utilized commands in manual G-code programming:*

- *G00: Moves tool to a given position →* G00 X15 Y19
- *G01: Moves the tool at a given feed rate →* G01 X15 Y19 F200 *(F = feed rate)*
- *G02/03: Moves the tool in a CW/ACW manner →* G02 X27 Y38 I-12 J-16 *(I = X center offset | J = Y center offset)*
- *G17/18/19: Provides the plane at which the machine operates →* G17 = XY | G18 = XZ | G19 = YZ
- *G28: Returns the tool to its home/original position →* G28 X15 Y12 *(the X and Y are an intermediate position that the tool goes to before it gets back to its home position, used for avoiding collision)*



M-code: *M-code, also known as miscellaneous function, is the part of the machine's program that controls any non-geometric action such as spindle speed, turning on or off certain aspects of the machine like the coolant, changing spindle gear, and more. Just like the G-code, the way that the M-code works is that the line is initially written as "MXX" with XX relating to the command to be chosen, and after that – depending on the command – another command would have to be inputted such as the tool to be controlled. The following are some examples of the most commonly used M-code commands:*

- *M00: Stops the currently ongoing operation.*
- *M03: Rotates the spindle clockwise*
- *M06: Changes the tool →* M06 T12 *(Switches to tool 12)*
- *M07/08: Turns on or off the coolant respectively*
- *M95/96: Mirrors the operation on X-axis (M95) or Y-axis (M96)*

Cybersecurity

Potential security threats:

What are security threats:

Security threats could come in a variety of forms, and in software, threats could either target two things, the safety of the computer itself and the data within it, or the safety of the user by utilizing the computer for the malicious purposes. As such, the following section will talk about the potential threats seen in both CAD computer systems as well as CNC controllers.

Weak password protection:

A "weak" password could be defined as a password that is either too easy to guess or has an obvious relation to the user such as their pet's name or their birthdate. However, even if a password were to be relatively strong, threats related to it could potentially arise from either writing it down in an secured location – physical or digital – or by trusting people with said password, which could lead to them or someone they have told opening the system for malicious intents. The reason that most people would utilize weak passwords is mostly for convenience as most would not bother change their passwords on regular basis or memorize ones that are too difficult. However, having access to the password of a system grants attacker with almost full ability to apply changes or access any file within the system. Another danger to having weak passwords is the fact that attackers could utilize a brute force method in order to guess the password, in that they could simply have a software program submit thousands of passwords at a time until one is accidentally guessed correctly, with tis process becoming significantly longer and harder the more difficult the utilized password is.

Having weak password protection can affect CAD computer as many sensitive files such upcoming design models could potentially be stolen, while having weak passwords for CNC controller systems could lead to them being used by unauthorized personnel for malicious reasons with the main ones being changing the machine's G/M-code in order to hurt the quality of the product being machine or damage the machine itself.

DDoS:

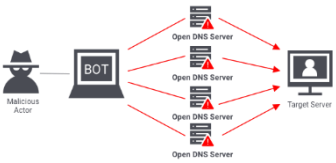


Figure 25 - How a DDoS attack works

A DDoS attack – an abbreviation for Distributed denial of service – is a form of attack launched by requesting data from a given server or network in a simultaneous and rapid manner, which consequently overloads that network, causing it to stop functioning appropriately. This could be done in a variety of manners, but one of the most common ways is for the attacker to utilize a large number of different computers or even household utilities that have internet connectivity such as microwaves or fridges (IoT devices) in order to send a number of similar or varying requests to the network such as data request messages like Echo/Ping requests.

Although DDoS attacks are mostly used to target website hosting servers, they can be used for attacking any network connected to the internet such as a company's personal network. This would severely hurt CAD computers as they would not have access to the internet, and although most CAD services do not require internet connectivity, many operations are done through the internet such as transferring files utilized for models or downloading necessary components for the modeling process. Although the damage would be less severe to CNC controllers as their use of the internet would mostly consists of file transfer and process monitoring, it nonetheless would potentially cause an issue especially if something were to not work as expected, not being able to monitor the CNC machine could potentially cause damage to the machine itself or the product being manufactured.

Social engineering:

When talking about information technology and software in general, social engineering refers to the use of deception and human manipulation in order to extract information or gain access to a given system for malicious purposes. Although social engineering could be done a variety of methods, the ones most prominently utilized by attackers are Scareware, baiting, and pretexting. Scareware refers to scaring a person using death threats or potential of robbery into providing confidential information, while baiting is the opposite, where the victim is given enticing offers such as free movies or services which leads to them unknowingly providing personal information, finally, pretexting is the process of making up a fake scenario such as calling or messaging someone pretending to be a superior asking for information, leading to employees providing said info without knowing that the person talking to them is not actually a superior. All of the aforementioned attack techniques could be done using any platform that allows users to talk with each other such as emails or social media platforms, however, they could also be done physically by talking to the victim in real life.

Social engineering could be used to extract confidential information that could be used for malicious activity on both the CAD computer systems as well as CNC controllers, as social engineering could lead to an attacker accessing the system itself which consequently could be used to extract and leak information from the CAD computer or utilize the CNC machine for malicious purposes.

Using unsecured networks:

Using an unsecured network refers to being connected to a WiFi connection with either no form of security measure such as a password whatsoever or the security measures in place are extremely weak. The way that an two devices are able to contact each other is through the use of a central connection or router, as anything being that a given computer system is trying to transfer wirelessly would have to initially pass through the modem or the central WiFi connection of the network system, which in turn relays the information to the location the data is supposed to be transferred to. The main issue with this is that if an attacker were to have easy access to the same network that a computer system is utilizing, the attacker would be able to detect the packages and data being sent from the computer system to the router, which would be done by acting as a middle main connection between the computer system and the server, in that any request that the computer sends would initially go through the attacker, and then to the server, and vice versa from the server to the computer. This is also why these types of attacks are known as "Main-in-the-Middle" attacks, or MITM for short. Additionally, since the MITM acts as a transfer point for the data gotten and received by the computer server and router, the MITM would be able to alter the data being sent, potentially leading to them sending malicious links or websites that could download dangerous malwares or act as a keylogger to detect passwords.

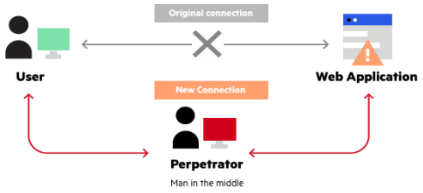


Figure 26 - MITM attack

Utilizing unsecured networks could potentially sever damages to a manufacturing company's if the vulnerabilities within the network were to be well exploited by the attacker. This is the case since having a MITM attack occur to a CAD computer is an extremely dangerous threat, as using the aforementioned process of altering the data being sent to the computer system, the attacker could potentially install malware into the computer system, and therefore have access to all the information that it has. Moreover, even without altering the data being transferred, being able to see the data being sent from the computer system to the router means that the attacker could potentially access confidential CAD models and design ideas. Furthermore – and the reason to which unsecure networks are extremely dangerous – is due to the fact that the attacker could potentially alter packets being sent to the CNC machine, with said packets having the probability of containing G-code or M-code that was meant for editing machine commands, consequently allowing for the attacker to control the operations of the CNC machine. This could lead to damages to the product and the company's reputation on a major scale, as changes in the machine G/M-code in a malicious intent could lead to deformation in the final product that could hurt the overall quality of

the product and potentially the safety. Additionally, this could be used to alter the machine's code and cause the tools to move to an inaccessible position that would cause collision and consequently damage the machine.

Malware:

What is malware: *Malware refers to any computer software or code created specifically with malicious intents; this could range from software developed to extract information, disrupt a given computer, access unauthorized systems and the data they hold, unknowingly track users, and so on. Most malware software programs rely on the initial user error, in which that the user downloads the file containing the malware unknowing to the fact that the file contains it, which as a consequence generally leads to a successful attack. The term "malware" is very broad and could constitute of a variety of software attack methods, therefore some of the more popular malware attacks are going to be discussed separately in the following section:*

Different types of malwares:

Viruses and worms: *Viruses and worms are a form of malware that once installed on a computer system, its main task is to replicate and infect the rests of the system or even the network. Although similar in aim, viruses and worms differ in execution, with viruses, they spread manually using deception which tricks people into transferring these files from one computer system to the other, while worms are more advanced, in that once the worm is triggered and latched on a computer system, it automatically transfer itself from one system to the other within the network without requiring any kind of human intervention or assistance in order to do so. The actual job the viruses and worms do on a computer system drastically differs from one virus/worm to the other, with some being used to simply increase load on a network, which is why sometimes viruses would slow down network connection, while some other viruses/worms could potentially locate and edit or delete certain files. Either way, both worms usually come in the form of an executable file, meaning neither would be actually triggered unless they have been directly opened by the user, which is where the social engineering aspect of viruses and worms comes into play.*

Rootkit: *Rootkits are one of the more dangerous forms of malware used by attackers. A rootkit's main function is to be provide the attacker with complete control over the victim's computer and its operating system. The way that most rootkits work is that they are generally downloaded through untrustworthy sites or emails in the form of a computer system driver, which is the software that provides the operating system with instructions on how a given peripheral device works. The reason that rootkits hides themselves within driver downloads is that – as mentioned by* (Techquickie, 2015) *– computer drivers are generally stored in a part of the operating system's software known as the kernel, which can be said to be the most crucial part of the operating system as it controls communications between the computer system's software and hardware components. This means that when a rootkit is installed onto the system, it can control almost anything that occurs with the system and therefore provides the attacker with full control. Moreover, rootkits are harder to detect than other traditional forms of malware such as viruses and worms as they have been specifically designed for the purpose of remaining hidden, and since they have access to the entire system, they can disable security features that could generally assist in detecting them. This can lead to a full shutdown of the computer system including all the data it contains, with this not only being limited to CAD computers, but any device that utilizes an operating system and therefore utilizes a kernel, which includes CNC machines.*

Botnets: *Botnets are a type of malware that provides the attacker with access to certain parts of the computer that allow them to transfer data to other computer systems. This process is generally initiated by having a user download a seemingly meaningless or innocent file through social engineering, from there, the attacker is able to use the computer to transfer data to other devices. This can be used for a variety of reasons, mainly being initiating a DDoS attack, as attackers usually use infected computers to send signals to a given network or server to overload it. Furthermore, botnets could be used sending spam emails that contains viruses and means of malware, which generally causes the receiving computers to also become a botnet, essentially creating a large group of remotely controlled computers. This process utilizes a decent amount of hardware power due it being used to send a lot of*

data, therefore a significant decrease in computer performance could be noticed. Additionally, this could also be used to steal information for the computer system itself if a virus is accompanied with the botnet. This process mainly affects CAD computers and is not a point of concern for CNC controllers as their transferring functionalities are rather limited.

Spyware and keyloggers: *A spyware is a form of malware that specializes in – as the name might suggest – spying on the user of infected computer system. The way that spyware application works differs from one malware to the other, but generally, spyware accesses the computer's memory, and using that, it is able to read data being sent to the device. Another method that spyware could be installed into a person's computer is by tricking the victim using social engineering techniques into downloading a remote administration program, which allows the attacker to access the victim's computer with relative ease. Type of spyware could include tracking a person's emails and any financials they have made or using a keylogger to log anything that the user might have typed onto their keyboard, potentially including sensitive information such as password, financial details, or any other confidential information.*

Ransomware: *Ransomware – as the name might suggest – is the process of utilizing a malware installed onto the victim's computer that locks most or even all of the information and data that they might have on their system, and demanding a ransom (a sum of money) for malware to be pulled back. This process is generally done through gaining either access to administrative privileges of the computer and then removing the victim from the admin list or by encrypting the data and turning it into an unreadable form, that would only be decrypted after the ransom has been paid, moreover, certain types of ransomware also include data exfiltration, which is the process of transferring data from the victim's device to the attacker, which acts as an added layer of fear that the attacker could use against the victim, as the data transferred could potentially be used for blackmailing purposes.. Other types of ransomwares include "locker" ransomware, in which, the malware blocks access of the entire computer's basic function such as using the keyboard and mouse until the payment has been made.*

Fileless attacks: *Fileless attacks are attacks that utilize a legitimate software application in order to run commands that in turn could be used for malicious intents. Said attacks generally follow a given process, in which the victim initially clicks on an untrustworthy link or downloads a suspicious file through the use of social engineering, from there the downloaded file or opened website gotten from the link that has been c licked opens a legitimate application, and using normal commands from that application, the attacker is able to gain access to the computer's command or PowerShell interface, in which, they are able to transfer data t o them personally or manipulate and access the computer system's files. This type of malware is known for being extremely dangerous due to it being very hard to track since – as the name says – it utilizes no files and therefore has no imprint that could potentially lead back to the attacker.*

Trojans: *Trojans, also known as trojan horses, are one of the most prominent methods and forms of malware. Said trojans act as a seemingly safe to install application or file that – when installed – releases any potential malware that it holds, with said malware ranging from any of the aforementioned ones, with the trojan horse being in fact one of the main methods utilized for infecting a computer system with any of the previously mentioned forms of malware such as causing the computer system to become a part of a botnet group, infecting it with worms, viruses, spyware, ransomware, and any other types of malware available. Additionally, one of the major threats that trojan horse malwares cause is the difficulty to detect them since – as mentioned – they are downloaded as seemingly safe and legitimate software to the operating system and therefore even virus and malware prevention applications have a hard time in detecting them. As such, one of the more common uses of trojan horses is to provide what is called a "backdoor" to the attacker, which is an access point that they could use whenever they want to gain access to the victim's computer without the knowing.*

Security protection methods and improvements:

Relative threat CNC controllers vs CAD computers:

Between the two, CAD computers have a much greater need for utilizing and browsing the internet, from accessing company files that might be saved on the cloud, researching design ideas for a 3D model, looking up documentations for a given application or G/M-code documentations, and more. While on the other hand, CNC controllers have very limited use for the internet except for some newer machines that do employ internet usage for receiving files to be machined and remote monitoring and editing of the machining process.

As such, due to the majority of security threats available nowadays being related to cyber threats and cybersecurity, very little improvements to the protection of a CNC controller could be made as the simple fact of it not extensively using the internet makes it quite a safe machine from security threats. Therefore the following section would mostly discuss security threats related to that of CAD computers.

Employee policies:

Regular password changes: *One of the simplest yet certainly effective method of protecting against security and data breaches is simply having employees change their passwords on a regular basis. This simply means that even if an employee were to have their password stolen, unless the attacker acts upon it immediately, it is likely that they would not be able to actually do anything meaningful. However, it should be noted that even though the changes should be regular, the timing of said changes should not be consistent or in a certain patter, but rather should be random as to ensure that the attacker would not be able to anticipate when the passwords might be changed. Additionally, this could also be used for both CAD computers as well as CNC controllers as newer controller's on the market tend to come with password protection features.*

Teaching employees about social engineering techniques: *Teaching employees about what threats they should be looking out for when downloading files from the internet is key to ensuring that their neither their personal data nor the company's data are under threat of being breached due to social engineering attacks. As such, seminars should be made on a regular basis as well as sending courses to them which teaches them about phishing, pretexting, scareware, and baiting. To further protect from potential social engineering attacks, the platforms in which employees contact each other as well as superiors should be as little as possible as for employees to be able to easily differentiate between potential scams and social engineering attempts and genuine messages.*

Limit user privileges: *Limiting user privileges for certain aspects of a computer system to unauthorized employees is a great protection method that would ensure that if an employees computer were to be compromised, unless they have admin authority over their computer, the attacker would not be able to access every single item especially in a system where files are shared between one another.*

Physical locks: *Another potential way to prevent security breaches in real life rather than software only is to utilize physical locks that only open via certain keys or cards that are only given to authorized employees. This would prevent easy access to company property such as data and hardware devices to attackers that could potentially intend on stealing or damaging them using physical methods. This method would be extremely effective in also protecting CNC controllers as due to the lack of extensive internet connectivity, the only major threat to them is being physically accessed, and therefore utilizing physical locks would be able to almost completely secure the CNC controller systems.*

Implementing appropriate software measures:

Using a firewall: *A firewall is a protection method employed by either the operating system and is done locally on a given computer or done on a wider scale and protects an entire private network. A firewall program or utility software contains an immense library of preconfigured codes, packets, IP addresses, and data that could potentially*

contain information harmful to the computer or detect someone that could potentially try to intercept a connection by detecting a personal IP address that should not be going through the connection between the system and a given website. Using that library, the firewall scans incoming traffic that goes into or out of a network or computer system, and compares it with the codes available for it in its library, and if any of the traffic going into the system matches an item in the library, then the firewall would prevent that packet/data from going into the system. Basically, a firewall could be depicted as an actual gate that scans the IDs for all incoming traffic, and if an ID (the packet) matches a blacklisted ID (the codes from the library), then it would prevent it from passing through and going into the system.

Antimalware: *At its core, an antimalware software works very much like a firewall, in that it utilizes a massive library of different malware variations and codes that could harm the computer. However, the difference between an antimalware and a firewall is in the execution of the program, in that a firewall prevents malware and potential interceptions over a given network before they get to the system, while an antimalware works on detecting malware already within the system or that is being sent into the system via methods that do not utilize a network connection. Overall, an antimalware's job is to scan every file available on a given system, compare it with its library of malwares, and if a file within the system matches one of the libraries files, then the software would disarm the malware by deleting the file.*

Anti-DDoS: *An anti-DDoS service works initially just like a firewall and antimalware software utilities, in that it has a list of blacklisted IP addresses and packets that would not be allowed to pass on and go through the system. However, in addition to that, the anti-DDoS also filters out packets sent in particular patterns that would generally be used during DDoS attacks.*

According to (Alibaba Cloud, 2020)*, when a DDoS attack is initiated on a given network, a CDN system (Content Delivery Network) works, which takes all the filtered packets sent to the network during the DDoS attack are transferred into a server dedicated for handling the attack known as a "DDoS scrubber", said server simply acts as a placeholder for all the packets DDoS packets, as such, any traffic that was initially meant for the original server is taken to the scrubber, and consequently the genuine traffic of the networks flows as normal with very little to no stutter at all.*

File encryption: *As stated earlier within the ransomware section, file encryption is the process of rewriting the data within a given file into a format that cannot be read by either machine or human. Said format is formed using an encryption key, which utilizes a given algorithm to rewrite the data, as such, in order to decode the decode that encrypted data, the encryption key would have to be available to the attacker so that they are able to reverse the initial encoding processing by reverse engineering the algorithm to decode the file. This process is extremely effective as if an attacker were to get their hands on a given set of confidential files, they would not be able to access the information available within them. Therefore companies should employ the use of encryption software that encrypt company files, especially those of reasonably high importance.*

Implement VPNs: *A VPN, also known as a Virtual Private Network, is – as the name suggests – a private network that redirects a computer system's data to a privately owned network by the VPN provider, and from there redirect the computer system to the originally intended location such as a website. This main advantage of using such a process is that the private network is generally much more secure and encrypted than the networks and servers available by the website that was originally intended to be accessed, as such, any attacker trying to intercept the signal using a MITM method (Man-in-the-Middle) would not be able to see the type of data that is being transferred, with said data potentially including sensitive information such as financial details and passwords. Additionally, due to the DNS server being privately owned and encrypted, it would be much harder to redirect the signal using a DNS spoofing method according to* (kaspersky, 2022)*. Overall, this would prevent any potential interception and hacking attempts made at a given computer system in the circumstance that the attacker were able to bypass security the WiFi's security measures as even if the hacker would be able to see the traffic within the network, all the packets and data being sent would be encrypted and of no use to them.*

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"Whenever a man can get hold of numbers, they are invaluable: if correct, they assist in informing his own mind, but they are still more useful in deluding the minds of others. Numbers are the masters of the weak, but the slaves of the strong."

-Charles Babbage
The father of computing