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原文内容：

# Abstract

Video games have become a common occurrence in today’s world. In this paper I have looked at what makes 3D gaming possible. To understand 3D video games, the basics of 3D graphics are the starting point. To make a video game, you need to understand how a video game works.When making a video game, a layered approach is followed. The layered structure of a video game tells how it is built up and thus what you need to know to make one.

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# Introduction

Video games have become a common occurrence in today’s world. Just like other software, it has evolved over the years. For video games the biggest and most noticeable change has been made graphics wise. The first video games were in 2D i.e. in a two-dimensional plane.Today’s video games mostly are in 3D. The step from 2D to 3D graphics was made possible by technological progress in the computer industry. In this paper I want to look at what makes 3D gaming possible. Therefore I have the following questions:

·What does it take to make a 3D video game?

· What are basic concepts for 3D graphics?

· What are basic concepts for a video game?

·How do you put together the knowledge gained from the previous questions to

make a 3D video game?

I will devote a chapter per sub question. In the conclusion I will summarize the discussed material and give answers to the above questions.

# Basic concepts of 3D graphics

According to (Watt et al, 2001) the role of three-dimensional computer graphics in the context of computer games is to supply tools that enable the building of worlds, populating them with characters and objects, having these games objects interact with each other and ‘reducing’ the action to a two-dimensional screen projection in real time. None of this can be accomplished without knowledge of the basic mathematics of three-dimensional space. In this chapter I will talk about these basic mathematics, but I will not go into gory mathematical details. Instead, I will give a basic overview that serves as an introduction towards understanding 3D graphics in the context of 3D video games.

## 2.1. 3D coordinate system

It all starts with a three-dimensional coordinate system. This system has three axes: x, y and z.There are two common ways to arrange the (positive) axes: the right-handed and the left-handed system (figure 1 and 2).

**Figure 1 Left-handed coordinate system Figure 2 Right-handed coordinate system**

To determine with which system you are dealing, visualize wrapping one of your hands around the z-axis. Then look at the direction your thumb is pointing. If it points in the same direction, then the hand you used is also the name for the system. If not, the name for the system is the name of the other hand.

Although right-handed systems are the standard mathematical convention, both systems are

used. The difference between the two systems is the position the (positive) z-axis points to.

## 2.2. Objects

With the coordinate system in place, it is time to move on to the next topic: objects. At their

lowest level, three-dimensional objects are represented as a set of points in the coordinate system. For simple objects you could define points in the three-dimensional space and draw lines between them to form the object. For complex objects this would be a tedious job; therefore you need a different way to represent an object in 3D. In (Watt et al, 2001) a number of mainstream computer graphics models are mentioned:

1. Polygonal model.

Objects are approximated by a net or mesh of planar polygonal facets (polygons). In (Angel, 2003) a polygon is described as an object that has a border that can be described by a line loop, but has an interior. That is also the reason that it is sometimes referred to as fill area. With polygons you can represent objects to an accuracy of choice. More accuracy comes at the cost of using more polygons.

2. Bi-cubic parametric patches.

These are ‘curved quadrilaterals’. Generally it can be said that the representation is similar to the polygon mesh except that the individual polygons are now curved surfaces. Each patch is specified by a mathematical formula that gives the position of the patch in three-dimensional space and its shape. This formula enables us to generate any or every point on the surface of the patch. The shape or curvature of the patch can be changed by editing the mathematical specification. This results in powerful interactive possibilities. The problems are, however, significant. When the shape of individual patches in a net of patches is changed, there are problems in maintaining ‘smoothness’ between the patch and its neighbors. Bi-cubic parametric patches can either be an exact or an approximate representation. They can only be an exact representation of themselves, which means that any object can only be represented exactly if the shape corresponds exactly to the shape of the patch. This somewhat torturous statement is necessary because when the representation is used for real or existing objects, the shape modeled will not necessarily correspond to the surface of the object.

A significant advantage of the representation is its economy. When compared to the polygonal model, the bi-cubic parametric patches model uses fewer elements to create the same object.

3. CSG (constructive solid geometry).

This is an exact representation to model objects within certain rigid shape limits. It has arisen out of the realisation that a lot of manufactured objects can be represented by ‘combinations’ of elementary shapes or geometric primitives. For example, a chunk of metal with a hole in it could be specified as the result of a three-dimensional subtraction between a rectangular solid and a cylinder. Connected with this is the fact that such a representation makes for easy and intuitive shape control – it can be specified that a metal plate has to have a hole in it by defining a cylinder of appropriate radius and subtracting it from the rectangular solid, representing the plate. The CSG method is a volumetric representation: shape is represented by elementary volumes or primitives. This contrasts with the previous two methods that represent objects using surfaces.

4. Spatial subdivision techniques.

With this technique the object space is divided into elementary cubes, known as voxels and each voxel is labelled as empty or as containing part of an object. It is the threedimensional analogue of representing a two-dimensional object as the collection of pixels onto which the objects projects. Labelling all of three-dimensional object space in this way is clearly expensive, but it has found applications in computer graphics. This model thus represents the three-dimensional space occupied by the object; the first two mentioned methods are representations of the surface of the object.

5. Implicit representation.

Implicit functions are occasionally mentioned in texts as an object representation form. An implicit function is, for example:

**x2 + y2 + z2 = r2**

which is the definition for a sphere. On their own they are of limited usefulness in computer graphics because there are a limited number of objects that can be represented in this way. Also, it is an inconvenient form as far as rendering is concerned. However, it should be mentioned that such representations do appear quite frequently in three-dimensional computer graphics – in particular in ray tracing where spheres are used frequently – both as objects in their own right and as bounding objects for other polygon mesh representations. Implicit representations are extended into implicit functions that can loosely be described as objects formed by mathematically defining a surface that is influenced by a collection of underlying primitives such as spheres. Implicit functions find their main use in shape-changing animation; they are of limited usefulness for representing real objects. The method does show potential for modelling organic shapes. Metaballs (blobs) is an implicit modelling technique that is used for creating the aforementioned organic shapes.

From all the object models, the polygonal model is the de facto standard. The main reason is that it has low CPU requirements; however you have the accuracy/polygon count trade-off. Other object models like bi-cubic parametric patches and spatial subdivision techniques (voxels) are getting used more frequently for 3D games. Although these models have higher CPU requirements, their advantages over polygons are enough reasons to start using them. The emergence of faster CPUs and more available memory will also stimulate the usage of other available models.

## 2.3. Transformations

In (Watt et al, 2001) transformations are described as important tools in generating threedimensional scenes. They are used to move objects around in an environment, and also to construct a two-dimensional view of the environment for a display surface. The basic idea behind a transformation is mapping a point to another point using some kind of function. The possible functions correspond to the different kinds of transformations. The transformations used for computer graphics are called affine transformations. According to (Weisstein, 2004), an affine transformation is any transformation that preserves collinearity (i.e., all points lying on a line initially still lie on a line after transformation) and ratios of distances (e.g., the midpoint of a line segment remains the midpoint after transformation). In this sense, affine indicates a special class of projective transformations that do not move any objects from the affine space to the plane at infinity or conversely. From a computer graphics perspective this means that an object can still be represented in the user defined 3D coordinate system after a transformation.

Affine transformations can be represented by a matrix and a set of affine transformations can be combined into a single overall affine transformation by combining the separate matrices. This makes it possible to apply different kinds of transformations to a single object. For more information on the mathematical background of affine transformations and matrices, see (Angel, 2003).

The most basic and commonly used affine transformations in computer graphics are translation, rotation and scaling. In (Angel, 2003) shear is also presented as a basic affine transformation, because of its importance. However, since it can be created by applying a sequence of the aforementioned three basic affine transformations, I do not see it a basic affine transformation. I will now give short descriptions of translation, rotation and scaling. These are abbreviations from (Angel, 2003).

Translation is an operation that displaces points by a fixed distance in a given direction. Since

we are dealing with a 3D coordinate system, the translations take place in the three axis directions.

Rotation is in an operation that displaces a fixed point around a certain vector at a certain angle. For a given fixed point there are three degrees of freedom: the two angles necessary to specify the orientation of the vector and the angle that specifies the amount of rotation about the vector.

Scaling makes objects bigger or smaller in any (combination) of the three dimensions. Scaling transformations have a fixed point. To specify a scaling, you need to specify the fixed point, a direction in which you want to scale and a scale factor.

## 2.4. Summary of basic 3D graphics concepts

To understand 3D videogames, the basics of 3D graphics are the starting point. Firstly, a 3D coordinate system needs to be defined. Secondly, you need to choose how to represent you objects in your coordinate system. You can choose from different kinds of object models, each with their trade-offs. Currently the polygon (mesh) model is the de facto standard, but this is changing as faster CPU’s and more memory become available. Lastly, you need a way to manipulate the objects in your coordinate system. This can be done with affine transformations. The three most basic and commonly used affine transformations for computer graphics are translation, rotation and scaling. Any other affine transformation can be created by applying a properly chosen sequence of the aforementioned basic transformations.

# Basic concepts of video games

To make a video game, you first need to understand how a video game works. The first thing

you need to realise is that a video game is just a program that can be compiled and executed. Just like any other program it has a main function that is the first function to be called upon when it is executed. The structure of the main function can be represented as a flowchart diagram, as depicted in figure 3 (Kuffner, 2002).



**Figure 3 Flowchart diagram of the main function of a videogame**

The diagram above consists of five states. The three most important states for a video game are connected to each other in a loop. This loop is often referred to as the “game loop”. In (Howland, 2001) the game loop is described as a series of procedures for getting input and displaying output to the player and updating the game. Let us now look at each state and their meaning:

·Initialization (Starting the game)

According to (Howland, 2001) the initialization is as follows: “The beginning of every game usually consists of an animation sequence to show off some aspect of the game's story or background and an option menu for starting the game or changing various parameters that affect the game in some way. Those parameters often include sound volume, graphic options, multiplayer options, difficulty and starting level.” I agree that this is the way a videogame is started when you play it. But when think about it, these things are actually done in the so-called game loop, because the player inputs actions and the videogame responds by performing the appropriate action. The changes have to be updated internally and have to be outputted to the player. What I think is meant with initialization is that the necessary parameters are set, functions are called et cetera that are necessary so that the videogame can move from this state to the game loop. Examples of what could be done in the initialization state are checking and requesting memory, setting up a stack, load display drivers.

·Player input

(Howland, 2001) says the following: “The input gathering routines will take the player's input from whatever device they are using and store it in a way that the game can process it to make changes to the game internals.” Note that the stored input information is used in the next state (updating game internals).

·Updating game internals

Here is what (Howland, 2001) has to say: “The game updating routines are the real guts of the game. Everything from moving the player's character using their input, to the actions of the enemies and determining whether the player has won or lost the game is determined here.” Also, preparations are made for displaying the graphics.

·Displaying the screen

According to (Howland, 2001) the screen can be displayed in two ways: ”You can either draw everything to the screen at one time or what is more commonly done, set everything up to be drawn and then draw the screen afterwards. Drawing the screen can take longer than most processes in a game so you want to do it all at one time. Determining what is necessary to be drawn can take a relatively long time with all the checks your game could have, so it's best to do this before you actually try to commit your graphics to the screen or video hardware.”、

·Ending the game

(Howland, 2001) describes that normally when a game ends, an ending sequence is displayed, or at least something that says goodbye to the player. This description is in the same spirit as his description about starting a game: it describes this state from a player’s point of view. Again, I think that something else is meant, namely calling functions and setting values et cetera, so that the video game can be terminated in a normal way.

Now that I have given an overview of the how a game basically works, it is time to look at some interesting aspects from the game loop that are essential for a modern video game. I will focus on the updating of the game internals and more specifically on gameplay and artificial intelligence of a video game. Before I start with discussing these subjects, I would first like to take a look at the scenario of a video game.

## 3.1. Scenario

According to Webster’s dictionary a scenario is a preliminary sketch of the plot, or main incidents. In the context of video games the word scenario has the same meaning, but there is one more thing that should be taken into consideration: a video game is interactive. When making the scenario for a game, it is quite usual nowadays to have some kind of plot that connects the interactive elements of the video game. Even when there is no (real) story, the scenario should describe what is possible in a video game. This leads to the following view of what the scenario of a video game looks like:

·The scenario at least describes the interactive elements of the video games. This should be written down as much as possible in a non-technical way, because you are not programming (yet). These interactive elements determine the gameplay.

·The scenario can have a plot that connects the interactive elements to each other.This part of the scenario can be seen in the same way as a scenario from a movie or a play. Nowadays most video games have a plot. For some genres of games this can lead to quite ridiculous plots, for instance puzzle games. Other genres are very dependant of the plot and cannot exist without it. In this case the plot is equally and sometimes more important than the interaction. An example is the genre of role-playing games. In this case you will need a system to present the story to the players. There are various ways for doing this, as described in (Simpson, 2002). You could for instance use cut scenes or scripting.

With the scenario (partially) developed, the gameplay can be worked out further.You can do this by writing down more about it, or [when worked out enough] you can start with programming experiments to test it out.

## 3.2. Gameplay

The word gameplay is one of the keywords in video gaming today. As the word says, it determines how a game is played. Gameplay is influenced by a couple of factors:

·Scenario and genre

In the scenario at least the interactive elements of a video games are written down,which determine the basic gameplay form. What has not been mentioned earlier is choosing the right genre(s) for a game. Each genre brings along certain gameplay elements that may or may not suit the game scenario. It is possible to combine different elements from different genres to fit the scenario. So it is the combination of scenario and genre(s) and how it is worked out that determine the basic gameplay.

·Control and response

Very important refinements of the gameplay are how a game is controlled and how well it responds to player input.The game controls should be defined according to what the player expects and knows and/or should be as natural as possible. Also, for advanced players customizable controls are recommended. A well thought up control scheme can benefit the gameplay, because it lets the game be played more easily. Controlling a game bring up the issue of response. The player should always be able to see what the consequences of their actions are in the video game. The response time should always be as short as possible, according to the type of gameplay. For instance, in a race game you do not want a response time of 5 seconds when racing, because in that time span, something else has already happened.

·Viewpoint (camera)

Although the viewpoint does not affect the gameplay directly, its choice does influence the way the game is played. If the player has a wrong view of the game world, it is harder to make a decision. For 3D games the viewpoint is often referred as the camera. The idea behind this is that the camera follows the player to show the gaming world.

·Learning curve and ease of play

The last two factors of influence for gameplay are the learning curve and ease of play. I have placed these two together because they both deal with the level of difficulty in a game.

The learning curve is the initial difficulty encountered when first playing a game. This affects the gameplay in such a way that only if the player knows the basics about the game, he/she can effectively play it. Thus if the player do not know enough, the gameplay is reduced, since certain gameplay elements are missed. The ease of play is the difficulty you engage in the game after the learning curve. The player at least knows how the basic gameplay elements work. This does not mean that the player has mastered a game. In many games it is possible to set the difficulty. This usually affects how the game world responds to the player. In the next paragraph about artificial intelligence I will come back on this.

Because gameplay is the core of each game, it will determine if the player wants to play it or not. Where graphics are dependant of technology and show their age over time, well thought out gameplay can last forever.

## 3.3. Artificial intelligence

According to (Kelly, 2003), Artificial intelligence (AI) is a generic term for software that simulates an advanced level of intelligence to perform complex tasks. In video games AI is used by game developers to add an element of realism to challenge a human opponent and enhance the quality of the game (Kelly, 2003). This should provide a better and more realistic experience for the player. AI is usually applied to the elements of the game world the player cannot control or influence. A so-called non-playable character (NPC) is an example of this. There are different kinds of AI techniques available that can be used for video games. Three of these [commonly used] techniques are search algorithms, neural networks and finite state machines. In the following paragraphs I will discuss their uses in video games.

### 3.3.1. Search algorithms

Search algorithms can be used to solve path-finding problems. An example of a path-finding problem in a video game is an opponent who tries to locate the player.

(Kelly, 2003) discusses search algorithms as having a problem space model, which is the environment where the search is performed. This consists of a set of states of the problem and a set of operators that can alter the state. Although brute force search algorithms like depth-first and breath-first search always find their goal, they are usually not suitable for video games, since they can require lots of memory and are inefficient as they can explore a large number of possible states until the goal state is reached. The A\* (A star) algorithm is also a path finding algorithm, but unlike the brute force algorithms it is more efficient. For more information about A\*, see (Patel, 2003). Another search algorithm is the minimax algorithm. It looks ahead to try and anticipate what the opponent will do. This information is used to choose the best move that gives the computer the advantage (Kelly, 2003).

Whichever search algorithm is used depends on the video game. The trade-off that has to be made is speed versus accuracy. For most games, you don't really need the best path between two points. You just need something that is close. What you need may depend on what is going on in the game, or how fast the computer is. (Patel, 2003) talks about this trade-off in the context of A\*, but it can be generalized to search algorithms in general.

### 3.3.2. Neural networks

When talking about neural networks or neural nets (NN) the first question of course is: what is a neural network? (Sarle et. al., 1997) gives us the following answer: “There is no universally accepted definition of an NN. But perhaps most people in the field would agree that an NN is a network of many simple processors (‘units’), each possibly having a small amount of local memory. The units are connected by communication channels (‘connections’), which usually carry numeric (as opposed to symbolic) data, encoded by any of various means. The units operate only on their local data and on the inputs they receive via the connections. The restriction to local operations is often relaxed during training.”This definition brings up an interesting aspect that makes NN interesting for use in video games: its ability to learn. (Kelly, 2003) justly remarks that this feature makes them an interesting addition to any game as they can gradually adjust themselves to provide a more challenging experience for the player. About the training rules (Sarle et. al., 1997) has the following to say: “Most NNs have some sort of ‘training’ rule whereby the weights of connections are adjusted on the basis of data. In other words, NNs "learn" from examples, as children learn to distinguish dogs from cats based on examples of dogs and cats. If trained carefully, NNs may exhibit some capability for generalization beyond the training data, that is, to produce approximately correct results for new cases that were not used for training.”

(LaMothe, 1999) gives a couple of examples of NN video game applications:

·Environmental scanning and classification.

A neural net can be feed with information that could be interpreted as vision or auditory information. This information can then be used to select an output response or teach the net. These responses can be learned in real-time and updated to optimize the response.

·Memory.

A neural net can be used by game creatures as a form of memory. The neural net can learn through experience a set of responses. Then when a new experience occurs, the net can respond with something that is the best guess at what should be done.

·Behavioral control.

The output of a neural net can be used to control the actions of a game creature. The inputs can be various variables in the game engine. The net can then control the behavior of the creature.

·Response mapping.

Neural nets are really good at ‘association’, which is the mapping of one space to another. Association comes in two flavors: autoassociation, which is the mapping of an input with itself and heterassociation, which is the mapping of an input with something else. Response mapping uses a neural net at the back end or output to create another layer of indirection in the control or behavior of an object. Basically, we might have a number of control variables, but we only have crisp responses for a number of certain combinations that we can teach the net with. However, using a neural net on the output, we can obtain other responses that are in the same ballpark as our well defined ones.

(LaMothe, 1999) remarks that the above examples may seem a little fuzzy, and they are. The point is that neural nets are tools that we can use in whatever way we like. The key is to use them in cool ways that make our AI programming simpler and make game creatures respond more intelligently.

### 3.3.3. Finite state machines

In (Brownlee, 2002) finite state machines are described as follows: ”Finite state machines (FSM),also known as finite state automation (FSA), at their simplest, are models of the behaviors of a system or a complex object, with a limited number of defined conditions or modes, where mode transitions change with circumstance. Finite state machines consist of 4 main elements:

·States, which define behavior and may produce actions

·State transitions, which are movement from one state to another

·Rules or conditions, which must be met to allow a state transition

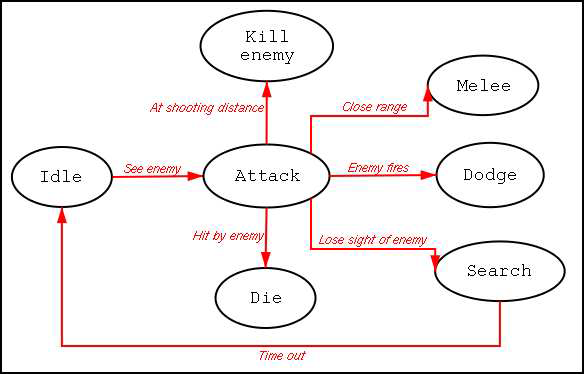
·Input events, which are either externally or internally generated, which may possibly trigger rules and lead to state transition

A finite state machine must have an initial state, which provides a starting point, and a current state, which remembers the product of the last state transition. Received input events act as triggers, which cause an evaluation of some kind of the rules that govern the transitions from the current state to other states. The best way to visualize a FSM is to think of it as a flow chart or a directed graph of states, though there are more accurate abstract modeling techniques that can be used.” Figure 4 shows a picture of a FSM by (Brownlee, 2002).



**Figure 4 A possible finite state machine control system implementation**

Now that we know what a FSM is, let us look at how we can use it for a video game.A few examples of videogames that use FSMs are the first person shooter (FPS) games Doom, Quake and Quake 2, which were all made by the same company, id Software. (Matthews, 2000) has an interesting example dealing with how the bots (NPC opponents) behave in his Quake 2 mod(ication). I have used his original FSM diagram to make figure 5.



**Figure 5 Finite state machine of a Quake 2 mod**

Let us take a look at the behavior of the bot. Firstly the bot will be in the idle state, doing nothing. When he sees the enemy, it will go to the attack state. Depending input events the bot receives while in this state, the bot will choose the appropriate follow-up action. Although figure 5 is a simplified model, it does make clear how a FSM works.

Finite-state machines are a good way to create a quick, simple, and sufficient AI model for the games it is incorporated in (Matthews, 2000). This also has its disadvantages. (Brownlee, 2002) justly remarks that for computer games, easily predictable behavior is usually not a wanted feature, as it tends to remove the ‘fun-factor’ in the game. He mentions possibilities to extend the FSM to make it harder to predict (NPC) actions: “A number of extensions to finite state machines such as random selection of transitions, and fuzzy state machines shows us another common type of FSM called non-determinist where the systems actions were not as predictable, giving a better appearance of intelligence.”

## 3.4. Summary of basic video game concepts

To make a video game, you first need to understand how a video game works. The first thing you need to understand is that a video game is just a program with a main function. The main function consists of five states. The three most important states for a video game are connected to each other in the game loop, which is a series of procedures for getting input and displaying output to the player and updating the game. Some interesting aspects from the game loop that are essential for a modern video game are gameplay and artificial intelligence of a video game. However, it all starts with the scenario.

The scenario should describe what is possible in a video game. It should at least describe the interactive elements of the video games, which is the base for the gameplay. Furthermore, the scenario can have a plot that connects the interactive elements to each other. Nowadays most video games have a plot. With the scenario (partially) developed, the gameplay can be worked out further.

Gameplay determines how a game is played. Gameplay is influenced by a couple of factors: scenario and genre, control and response, viewpoint (camera) and the learning curve and ease of play. Because gameplay is the core of each game, it will determine if the player wants to play it or not.

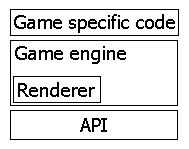
Artificial intelligence (AI) is a generic term for software that simulates an advanced level of intelligence to perform complex tasks. In video games AI is used by game developers to add an element of realism to challenge a human opponent and enhance the quality of the game. This should provide a better and more realistic experience for the player. AI is usually applied to the elements of the game world the player cannot control or influence. There are different kinds of AI techniques available that can be used for video games. Three of these techniques are search algorithms, neural networks and finite state machines.

# Making a 3D video game

In this chapter the knowledge from the previous chapters is put together to prescribe how to make a video game. The first thing we need is a game engine. (Simpson, 2002) makes a clear distinction between the game and game engine by making a comparison: “Many people confuse the engine with the entire game. That would be like confusing an automobile engine with an entire car. You can take the engine out of the car, and build another shell around it, and use it again. Games are like that too. The engine can be defined as all the non-game specific technology (for instance the renderer). The game part would be all the content (models, animations, sounds, AI, and physics), which are called 'assets', and the code required specifically to make that game work, like the AI, or how the controls work.”

The engine on its turn is made on top of a so-called application programming interface (API). An API is a set of functions you can use to work with a component, application, or operating system. For PCs, it provides a consistent front end to an inconsistent back end (Simpson, 2002). For game consoles both the front and back end are consistent. Nevertheless for both types of systems an API is necessary, because an API can ‘talk’ to the (graphical) hardware and make the necessary system calls.

The above described approach results in a layered video game structure (figure 6). A layered approach means that a layer can use functionalities/possibilities from the underlying layer that are presented to it (the higher layer).



**Figure 6 Layered structure of a video game**

In the following paragraphs I will discuss the three layers of figure 6 bottom-up.

## 4.1. Application programming interface (API)

Like stated earlier, an API is a set of interfaces to access lower level services. The API that can be used depends on the system you want to develop a game for. For game consoles each has its own specialized API(s), since the hardware does not change. For PCs the APIs need to be more general, since there is a lot of difference between the hardware of PCs. However, what you tend to see is that when a new PC game is made, it tries to take advantage of the latest hardware as possible, but at the same time it tries to support ‘older’ hardware as well. This results in a trade-off between what the minimal configuration of your PC should be versus how much of the new hardware technology can be incorporated. Currently the two major APIs used on the PC are OpenGL and DirectX. OpenGL is a pure graphics oriented API, where as DirectX is a collection of APIs for graphics, input handling, sound et cetera. The OpenGL counterpart of DirectX is Direct3D. There is an ongoing discussion on whether OpenGL or Direct3D is better. In (Roy, 2002) both are discussed through a thorough analysis without favoring one. I agree with (Roy, 2002) that you should choose for a certain API (or both!) depending on your situation and platform. In the end it does not matter which one you choose, because once you have learnt one of them, it is should not be too hard to learn the other.

## 4.2. Game engine

The game engine is built on top of an API and consists of the non-game specific technology. It is very common to give a game engine the name of the first game that used it. A classic example of a game engine is the Quake engine.

The game engine is not the same as the renderer. The renderer only makes up the graphical part of a game engine. An engine can consist of much more than just a renderer, for instance it can have world editors, character editors, a gravity model and a collision model. There is no maximum to what an engine should contain. The examples could also be left out; it is just a matter of what you want to be in it. Keep in mind that if you want your engine to be reused for other games, it (preferably) should not contain any game specific technology.

As mentioned earlier the renderer is the graphical component of a game engine. It is the minimum a game engine should contain. (Simpson, 2002) gives a good impression of what the renderer does: “The renderer visualizes the scene for the player / viewer so he or she can make appropriate decisions based upon what is displayed. It is generally the first thing you tend to build when constructing an engine. The renderer is where over 50% of the CPUs processing time is spent, and where game developers will often be judged the most harshly. The business of getting pixels on screen these days involves 3D accelerator cards, APIs, three-dimensional math, an understanding of how 3D hardware works, and a dash of magic dust. For consoles, the same kind of knowledge is required, but at least with consoles you are not trying to hit a moving target. A console's hardware configuration is a frozen ‘snapshot in time’, and unlike the PC, it does not change at all over the lifetime of the console.

In a general sense, the renderer's job is to create the visual flare that will make a game stand apart from the herd, and actually pulling this off requires a tremendous amount of ingenuity. 3D graphics is essentially the art of the creating the most while doing the least, since additional 3D processing is often expensive both in terms of processor cycles and memory bandwidth. It is also a matter of budgeting, figuring out where you want to spend cycles, and where you're willing to cut corners in order to achieve the best overall effect. “ For more information about how a game engine looks like, I recommend the tutorial by the earlier mentioned” (Simpson, 2002).

## 4.3. Game specific code

The game specific code basically consists of the in the previous chapter described game loop, which contains the interactive elements that make up the gameplay and the AI. Also, all the things you cannot put in the game engine are part of the game specific code. You can think of specific character models, sounds, special collision models et cetera. As long as it is not contained in the engine, you can add it to this layer. Other features that are usually put in the game specific code are multiplayer/networking options and HUDs/menus.

When using an existing engine for your videogame you already have a good starting point. However, it is not unthinkable that you would like to add more functionality to the engine, because it is not always possible to put that in the game specific code. Depending on how the game engine is made up, it may be possible to extend it and add the desired extra functionality.

Lastly I would like to discuss the use of game editors. It is quite impractical to create an entire world just by coding. Nowadays many games make use of specially built editors. These editors allow for the creation of game worlds, placement of characters and objects, scripting et cetera in an easy way. It is not uncommon that the game editor is included (in a modified form) with the video game when it is released. This gives players the opportunity to build their own worlds to play in and thus can extend the lifetime of the video game. A step further is a so-called mod(ification), which allows for the modification of the game specific code and sometimes even (parts of) the engine. A very well known mod is Counterstrike, which was made based on the Half-Life engine. It even got released as a new (separate) video game.

## 4.4. Summary of making a 3D video game

When making a videogame, a layered approach is followed (figure 6). Bottom up the layers are API, game engine and game specific code.

An API is a set of interfaces to access lower level services. The API that can be used depends on the system you want to develop a game for. For game consoles each has its own specialized API(s), since the hardware does not change. For PCs the APIs need to be more general, since there is a lot of difference between the hardware of PCs. Currently the two major PC APIs used are OpenGL and DirectX.

The game engine is built on top of an API and consists of the non-game specific technology. The game engine is not the same as the renderer. The renderer only makes up the graphical part of a game engine. There is no maximum to what an engine should contain. If you want your engine to be reused for other games, it (preferably) should not contain any game specific technology.

What the renderer does is visualizes the scene for the player / viewer so he or she can make appropriate decisions based upon what is displayed. It is generally the first thing you tend to build when constructing an engine.

The game specific code consists of the game loop, which contains the interactive elements that make up the gameplay and the AI. Also, all the things you cannot put in the game engine are part of the game specific code. Other features that are usually put in the game specific code are multiplayer/networking options and HUDs/menu’s.

When using an existing engine it may be possible to extend it to add extra functionality you need for your game.

Game editors allow for the creation of game worlds, placement of characters and objects, scripting et cetera in an easy way. It is not uncommon that the game editor is included (in a modified form) with the videogame when it is released. This gives players the opportunity to build their own worlds to play in. A step further is a so-called mod(ification), which allows for the modification of the game specific code and sometimes even (parts of) the engine.

# Conclusion

In the introduction I asked the following questions:

·What does it take to make a 3D video game?

·What are basic concepts for 3D graphics?

·What are basic concepts for a video game?

·How do you put together the knowledge gained from the previous questions to make a 3D video game?

I will now give answers to each sub question.

·What are basic concepts for 3D graphics?

Firstly, a 3D coordinate system needs to be defined. Secondly, you need to choose how to represent you objects in your coordinate system. You can choose from different kinds of object models with their trade-offs. Currently the polygon (mesh) model is the de facto standard, but this is changing as faster CPU’s and more memory become available. Lastly, you need a way to manipulate the objects in your coordinate system. This can be done with affine transformations. The three most basic and commonly used affine transformations for computer graphics are translation, rotation and scaling. Any other affine transformation can be created by applying a properly chosen sequence of the aforementioned basic transformations.

·What are basic concepts for a video game?

The first thing you need to understand is that a video game is just a program with a main function. The main function consists of five states. The three most important states for a video game are connected to each other in the game loop, which is a series of procedures for getting input and displaying output to the player and updating the game. Some interesting aspects from the game loop that are essential for a modern video game are gameplay and artificial intelligence of a video game. However, it all starts with the scenario.

The scenario should describe what is possible in a video game. It should at least describe the interactive elements of the video games, which is the base for the gameplay. Furthermore the scenario can have a plot that connects the interactive elements to each other.

Gameplay determines how a game is played. Gameplay is influenced by a couple of factors: scenario and genre, control and response, viewpoint (camera) and the learning curve and ease of play. Because gameplay is the core of each game, it will determine if the player wants to play it or not.

Artificial intelligence (AI) is a generic term for software that simulates an advanced level of intelligence to perform complex tasks. In video games AI is used by game developers to add an element of realism to challenge a human opponent and enhance the quality of the game. This should provide a better and more realistic experience for the player. AI is usually applied to the elements of the game world the player cannot control or influence. There are different kinds of AI techniques available that can be used for video games.

·How do you put together the knowledge gained from the previous questions to make a 3D video game?

To make a 3D videogame, a layered approach is followed (figure 6). Bottom up the layers are API, game engine and game specific code.

An API is a set of interfaces to access lower level services. The API that can be used depends on the system you want to develop a game for.

The game engine is built on top of an API and consists of the non-game specific technology. The game engine is not the same as the renderer. The renderer only makes up the graphical part of a game engine. There is no maximum to what an engine should contain. If you want your engine to be reused for other games, it (preferably) should not contain any game specific technology.

What the renderer does is visualizes the scene for the player / viewer so he or she can make appropriate decisions based upon what is displayed.

The game specific code consists of the game loop, which contains the interactive elements that make up the gameplay and the AI. Also, all the things you cannot put in the game engine are part of the game specific code. Game editors allow for the creation of game worlds, placement of characters and objects, scripting et cetera in an easy way. It is not uncommon that the game editor is included (in a modified form) with the videogame when it is released. This gives players the opportunity to build their own worlds to play in. A step further is a socalled mod(ification), which allows for the modification of the game specific code and sometimes even (parts of) the engine.

And now for the answer to the main question:

·What does it take to make a 3D video game?

The layered structure of a video game tells how it is built up and thus what you need to know to make one. You will need to start out by getting (read: buying or building) a game engine. Furthermore, you will always need knowledge of 3D graphics, since in a game engine (renderer) you will always need to deal with it. Finally you must have knowledge of how a video game works. Otherwise you cannot develop the scenario, gameplay, AI et cetera.

The above answer is of course not everything there is to making a video game. Building video games also takes a lot of experience. But when you look at making a game from a theoretical viewpoint as I did, I think that what I have described in this paper makes sense.

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翻译：

# 3D游戏概论

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# 摘要

在现今的社会中，电子游戏已经变得随处可见。在这边文章中，我将探讨是什么使得3D游戏能够出现。要想理解3D游戏，首先了解三维图形的基本知识。在开发一个电子游戏之前，你首先需要知道电子游戏是怎么运行的。游戏开发过程中，需要遵循分层开发的原则。电子游戏的分层结构表明了它是怎么构建，这是电子游戏开发中不可避免的一部分。

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# 一、前言

当今的世界上，电子游戏变得随处可见。同其他的计算机软件一样，电子游戏也已经发展了好多年了。对于电子游戏来说，最大和最值得注意的挑战是使显示的画面显得很生动，富有智慧和生气。最开始的电子游戏都是2D的，例如在二维平面上飞行的飞机。

现代的电子游戏几乎都是3D游戏。计算机产业的技术进步使得从2D到3D的这一步跨越成为了可能。在这篇文章中，笔者将探讨是什么使得3D游戏成为了现实。在这之以前，我有如下问题：

·开发一个3D游戏需要什么？

·3D图形的基本知识有哪些？

·电子游戏的基本知识有哪些？

·如何将前面说的应用到3D游戏之中？

笔者将会为每一个子问题开一章单独进行详述。在总结一章中，我将会总结所有的材料然后为上述问题给出答案。

# 二、三维图像的基本知识

根据Watt et al, 2001，计算机三维图像在电子游戏中扮演着支持那些用于构建游戏世界、角色和对象，并且使它们能够互相作用并且能够将其投影到二维屏幕上的工具的角色。只有对三维空间有着数学基础才能实现上面的功能。在这一章中，笔者将会简单阐述相关数学基本知识，但是不会做详细的数学理论探讨。这仅仅是为帮助理解3D游戏中的3D图形的知识。

## 2.1 三维坐标系

首先从三维坐标系开始。该坐标系有三个左边：x,y,z。通常，有两种方式来表示这种坐标系：

左手坐标系和右手坐标系（图一与图二）。

图一 左手坐标系 图二 右手坐标系

如果想要检测你正在是用什么坐标系，只需要用手握住z轴，如果大拇指与z轴方向相同，那么你用的那只手，就是哪种坐标系。

虽然数学上惯例使用右手坐标系，但是实际应用者，二者都有使用。二者唯一的差别就是z轴的指向的方向相反。

## 2.2 对象

坐标系已经有所了解，那就该了解下一项：对象。在最底层的实现中，三维对象被表示为坐标系中的一系列点。对于简单的对象，你可以在三维空间中定义一些点，通过在点之间连线来构建对象。但是对于复杂的对象来说，这是不可行的。因此，你需要一种不同的方法来表现三维的对象。(Watt et al, 2001)中提到了以下主流计算机图像模型。

1. 多边形模型

对象一系列的多边形来填充形成立体。在 (Angel, 2003)中，多边形被定义为使用一系列的线形成的具有边界的闭合对象，但是其拥有内部空间。这也是其有时也指内部填充区域的原因。通过多边形来描述物体，可以使得物体表现时有着不同的精度。使用的多边形越多越复杂，物体表现也就越准确。

1. 双三维参数块

首先应该了解一下“曲面四边形”的概念。一般来说，这个概念类似于多边形填充只不过在这里，单个多边形是一个曲面。每一小块都是通过数学公式来计算出其在三维空间中位置和形状的。公式使得我们可以计算出块表面上的所有的点。块的形状可以通过修改数学公式来改变。这导致了强大的相互作用，意义重大。当某一个块的形状发生改变时，保持该块与邻接的块的平滑是一个重要的问题。双三维参数块可以是一个准确或者是近似的表现。对于自身，他们只能准确的表现。这意味着，一个物体的形状如果与块的形状精确的一致，那么，该物体只能被准确的表达。这种令人纠结的状态是必须的，因为表现真实对象时，物体实际形状未必与表面一致。

这种模型的最大优势在于它的花费。与多边形模型相比，创意同一个对象，双三维参数块花费使用的元素数量更少。

1. 立体几何

这是对模型对象在刚性限度内的准确表示法。它有意识到很多高级对象可以表示为初级形状或几何基元的组合。例如，一个有一个洞的金属块可以表示为一个长方体和圆柱体的差集。将其联系起来，我们可以看到这样表达有利于进行简单和直观的控制——如果一个金属板上有洞，那么就可以定义一个圆柱体，将其与一个长方体做减法来得到这样的一块板。

立体结合法是一个体积表现法：形状是由初级形状或几何基元的组合而来。这与上面两个方法使用表面不同。

1. 空间剖分技术

通过这项技术，对象空间被分割为基本的立方体——体元，每一个体元要么被标记为空要么被标记为对象的一部分。这类似于二维空间中的像素。如果将所有的三维对象空间都进行标记，那么花费是非常大的。但是它在计算机图形学中得到了很好的应用。

这个模型使用三维对象占用的空间表现，最前两种方法使用对象的表面来表现。

1. 隐式表达

隐函数偶尔在文章中作为一种对象表示形式被提到。

隐函数是球体的定义法，例如：

x2+y2=z2

他们本身的作用很有限，因为很少有对象能够按照这种方法来表现。就渲染的形式而言，这种方式也不方便。但是，应当注意到，这种表现形式经常在三维计算机图形学中,尤其是在球体使用频繁的光线追踪,对象本身和边界都是多边形网格表示。

隐式表达可以延伸到隐式函数，可以松散地描述为对象由数学上定义的一个受底层参数影响的表面的集合例如球。隐式函数在变形动画中发挥着作用。对于表现真实的物体，它的作用很小。这种方法展现了它在塑造有机形状上的潜力。元球是一个隐式的造型技术,用于创建上述有机形状。

在所有的对象模型中，多边形模型是实际的标准模型。主要原因在于该模型对CPU要求比较低，然而会损失一部分的精度。但是其他的模型也开始在3D游戏中变得越来越常见。虽然这些模型对CPU要求更高，与多边形标准相比，他们的优点已经足够去使用它们了。CPU的发展和内存的进步也促进了这些模型的发展。

## 2.3 变换

在(Watt et al, 2001)中，变换被形容为三维场景产生的重要工具。其被用作将对象在环境中四处移动以及创造用于显示的二维平面。变换背后的基本原理是将一个点以某种方法映射到另一个点。不同的变换对应的方法不同。计算机图形学中用到的变换称为仿射变换。根据(Weisstein, 2004)，任何保留共线性（开始前所有点在一条之前上的，变换后依然在一条直线上）和长度比例（某个点变换前是线段的中点，变换后依然是中点）的变换是仿射变换。在这种情况下，仿射是一种不会从无穷远移动的特殊的投影变换。从计算机图形学的角度来说，变换只会在预定义的三维坐标系中进行。

仿射变换可以使用矩阵来表示，许多的仿射变换的结合可以使用矩阵运算来表示。这使得对一个对象进行多种变换成为可能。想要了解更多仿射变换地数学背景和矩阵，可以参见(Angel, 2003)。

在计算机图形学中，仿射变换最常见和最基本的用途是平移、旋转和缩放。因为剪切的重要性，在(Angel, 2003)中提出了剪切也是一个基本的仿射转换。但是由于剪切可以通过上述三种方式组合来实现，所以我不认为它是一种基本的仿射变换。我会给出平移、旋转和缩放的简单定义，这些定义源自(Angel, 2003)。

平移是将所有点点沿某个确定的方向移动相同的距离的操作。由于我们是在三维坐标系中进行处理，所以平移将会有三个坐标方向。

旋转是以一个固定点为圆心，沿着某个向量移动特定角度。 对于一个给定的不动点有三个自由度数：两个角指定的向量方向和一个角指定旋转的角度。

缩放用于在三维空间中放大或者缩小对象。缩放变换有一个不动点。你需要确定这个不动点和缩放方向以及缩放因子来进行缩放。

## 2.4 总结

要理解3D游戏，三维图形的知识是必须的起点。首先，需要定义一个三维坐标系，再者，你需要确定怎么在坐标系中来表现你所选取对象。你可以选取不同的对象模型，当然有取也有所得。目前，多边形模型是事实的标准，但这正在发生着改变因为，cpu变得越来越快，内存也变得越来越多。最后，你需要有一种方法在坐标系中操作你的对象。这可以通过仿射变换来实现。最常用和最基本的三种仿射变换是平移、旋转和缩放。其他的仿射变换都可以通过这三种按照特定的顺序组合出来。

# 初识电子游戏

为了制作一个电子游戏，你需要明白电子游戏是怎么运作的。首先，你需要认识到电子游戏也仅仅是一个可编译和运行的程序。就像其他的程序一样，main函数也是它第一个被执行的函数。Main函数的结构如图三所示的流程图一样。



图三

上图包含了五种状态，电子游戏最重要的三种状态在循环中互相连接，这个循环通常称作游戏循环。在(Howland, 2001)中，游戏循环被描述为获取输入，输出给玩家，更新游戏的一系列程序。让我们看看每个状态和它的意义：

·初始化（开始游戏）

按照(Howland, 2001)的说法，初始化是：“每个游戏的开始部分，通常包含了一个动画序列来接受游戏的故事或者背景和选项目录来开始游戏或者改变游戏的一些参数。这些参数通常包括音量、图像选项，多玩家选项、难度和开始的等级等”。

我同意，当你玩游戏的时候，游戏是已经开始了。但是如果深思，这些事情在游戏循环中都已经完成了，因为玩家输入能够成功，游戏也能以一种合适的方式做出响应。这些改变需要在循环内进行更新并且输出给玩家。我认为，初始化将必要的参数都设置了，必要的函数都调用了等等于是，游戏可以由初始化转换到游戏循环中去。初始化一般会做检查、请求内存，设置栈，加载显示驱动等。

·玩家输入

(Howland, 2001)中有以下说法：“输入采集协程会从玩家所使用的输入设备中获得输入信息，并在游戏内以游戏能够处理的方式存储用来改变游戏内部状态。”注意，采集信息是用于下一个状态（更新游戏内部）。

·更新游戏内部

(Howland, 2001)中提到：“游戏更新协程是游戏真正的心脏，从根据玩家的输入移动玩家的角色到敌人的动作反应已经判定游戏的输赢在内的所有事在这里决定。同时，也为显示做准备。

·屏幕显示

根据(Howland, 2001)，有两种方式可以在屏幕上进行显示：“你可以一次性在屏幕上绘制出所有东西，或者按照通常地做法，设定好所有东西然后再进行绘制。绘制花费的时间比游戏中其他大多数过程都要长，所以最好一次性进行操作。决定绘制那些东西将花费相对比较长的时间来进行你游戏中的所有检查。所以最好在真正的执行绘制之前将这个过程做完。

·结束游戏

(Howland, 2001)中描述说，正常情况下，当游戏结束时，结束动画将会播放显示，或者说至少有个提示结束的。这个描述就如同游戏的开始状态的描述一样：从玩家的角度来描述了这个状态。另外，我认为其他的一些事情例如调用函数保持数值等等也是很有意义的，这使得游戏能够正常的终止。

我对游戏是怎么运作的给了一个概述。现在我们应该聚焦到现代游戏的游戏循环中所必须的一些有趣的方面。我会着眼于游戏内部的更新以及更偏重于电子游戏的玩法和人工智能。在讨论这些之前，我们先讨论一下游戏方案

## 3.1 游戏方案

根据韦氏词典，方案是情节的初步草图或者主要事件。在电子游戏的内容中，方案有着一致的意义，但是需要考虑更多的东西：游戏是交互性的。

当制作游戏的方案时，有很多连接电子游戏交互元素的情节是很平常的。甚至在没有故事情节的时候，方案应当描述了游戏中可能发生的事情。对于游戏方案有以下的观点：

·游戏方案至少描述了游戏的交互。这应当以不包含技术实现的方式尽可能详细的写下来，因为此时还没有开始编程。这些交互元素决定了游戏玩法

·方案中应该有连接各个交互元素的过渡。方案的这部分就如同电视剧或者电影的剧本一样。现如今，绝大多数的游戏都有故事情节。一些流派的游戏可能会有相当荒诞的情节，例如实时解密游戏。但是其他的流派的游戏都是忠于剧情的，不能离开情节而存在。在这种情况下，情节与交互一样有时候甚至更重要。一个典型的例子就是角色扮演类游戏。这种情况下你需要一个专门的系统来为玩家展现故事。在(Simpson, 2002)中提到了很多种方式。例如可以使用场景或脚本。

随着游戏方案（部分）的完成，此时可以开始设计游戏的玩法。

你可以通过尽可能详细的写出来，或者（在准备工作已经很详尽的情况下）开始尝试编程做出demo来测试。

## 3.2 游戏玩法

游戏玩法是电子游戏的关键词。就如同这个词的字面意思所说，它决定了游戏怎么玩。游戏玩法被以下的因素所影响：

·方案与游戏类型

在游戏方案中，至少交互元素要写上，因为它决定了游戏的基本玩法。在前面没有提到的是，要合理的选择游戏的类型。不同类型的游戏所包含的元素可能适合这个方案，也可能不适合。结合不同类型的不同元素来适应方案是可行的。所以，方案和类型的结合决定了游戏的基本玩法。

·操作方式与游戏反馈

对游戏的改进、优化来说，游戏中怎么操作以及对玩家的输入很好的反馈是很重要的。

游戏的操作应该根据玩家所想来定义使之变得自然、协调。同时，应当允许高级玩家自定义输入。一个精心思考过的控制方案对游戏的可玩性很有利，因为它使得游戏更容易上手。

游戏的控制会带来反馈的问题。玩家应该可以看到他们在游戏中的行动的顺序。游戏的反应时间应当越短越好。例如，你总不希望在一个竞赛游戏中，禁赛的反应时间需要五秒钟，因为如果真的需要那么长的时间，很多事情早就发生了。

·视角（摄像机）

尽管视角不会直接的影响到游戏的玩法，但是他的不同选择决定了游戏怎么来玩。如果玩家在游戏世界中的视角不对，玩家将很难做决定。对于3D游戏来说，是叫通常指的是摄像机。采用这个名字的原因，摄像机引导玩家观察游戏世界。

·学习曲线和玩法难度

影响可玩性的最后两个因素是学习曲线和玩法难度。我将这两者放在一起的原因是两者都是关于游戏难度的等级。

学习曲线是游戏新手初入游戏时所遇到的难度。由于玩家只有通过了解了游戏的基本知识，他才能很好的玩这个游戏。因此，如果玩家对游戏了解不够，游戏的可玩性就会减少，因为缺失了必要的元素

玩法难度是你经过学习曲线之后的游戏难度。玩家已经了解游戏的基本运作元素。但这不意味着玩家已经是游戏的高手了。经过很多句的游戏之后才能达到这个程度。这通常影响游戏世界对玩家的影响。在下一节关于人工智能的章节中，我会回顾这个问题。

由于游戏的可玩性是每个游戏的核心，它决定了玩家是否会继续玩下去。就像图像是游戏的技术基石，在游戏一直存在一样，可玩性一直存在。

## 3.3 人工智能

根据(Kelly, 2003)，人工智能是模拟高级智慧来完成复杂工作的软件的术语。在游戏中，人工智能被开发者用于为人类的对手添加一下真实元素，提高游戏的质量。这会为玩家提供更好、更真实的游戏体验。人工智能通常用于游戏世界中玩家不能直接控制或者影响的元素。非玩家角色（NPC）是这样的一个典型例子。有很多不同的种类的人工智能技术可以用于电子游戏之中。最常用的三种是搜索算法、神经网络和有限状态机。在这一节中，我会阐述他们在游戏之中的应用。

### 3.3.1 搜索算法

搜索算法可以用来解决寻路问题。一个典型的寻路问题是：玩家的敌人来定位玩家的位置。

(Kelly, 2003)中讨论了搜索算法有一个问题空间模型，即搜索执行的环境。其中包含问题的一系列状态已经一系列改变状态的操作。尽管蛮力搜索算法例如广度优先算法和深度优先算法总能实现他们的目标，但是通常他们并不适合于电子游戏，因为这些算法需要消耗大量的内存以及不够高效因为要遍历大量的状态来找到目标状态。A\*算法也是一个寻路算法，但是比蛮力搜索的算法要高效许多。要了解更多关于A\*算法的信息，参见(Patel, 2003)。

另一个搜索算法是极大极小值算法。他通过前一步来预测哪条路径更好。得到的信息用于选择能够给予计算机优势的移动路径。

采用哪一种算法取决于游戏。需要在速度和精确中做出取舍。对于大多数游戏，你并不是真的需要两点之间的最佳路径。你需要的只是近似最佳。你需要根据游戏中正在进行什么以及电脑的运行速度有多快来决定采用哪种算法。(Patel, 2003)谈到了A\*算法中的取舍，但是可以使得搜索算法能够一般化。

### 3.3.2 神经网络

当谈到神经网络的时候，第一个问题是：什么是神经网络？(Sarle et. al., 1997)给了以下答案：“神经网络没有一个得到普遍接受的定义。但是这个领域中的大部分人应该同意神经网络是有很多的简单处理单元组成的网络，每一个可能只有很少的内存。单元间通过信道连接，通常携带数字数据（而不是字符），可以被解码为各种意思。每个单元只能处理自己的数据以及通过信道收到的数据。本地操作的限制通常在训练的时候被放开”。

这个定义阐述了神经网络对游戏来说很有趣的一方面：学习的能力。(Kelly, 2003)只是标注了一下这个特征对于游戏来说是一个额外的优点就是逐步调整自己来为玩家提供更多的挑战。

对于训练规则，(Sarle et. al., 1997)有以下说法：“许多神经网络有许多种训练规则，这些规则在连接和基础数据的权重上不同。换一句话说，神经网络在例子中学习，就如同小孩子能够分辨猫和狗是因为见过了很多的猫和狗。如果用心训练，神经网络能够展现出超出训练数据的归纳能力，这意味着它们对于没有训练过的场景也可以得出一个近似的结论。

### 3.3.3 有限状态机

## 3.4 总结

# 如何开发3D游戏

## 4.1 应用程序接口

## 4.2 游戏引擎

## 4.3 游戏实现代码

## 4.4 总结

# 总结

# 引用