ADVANCED TOPICS IN SCIENCE AND TECHNOLOGY IN CHINA

Faxin Yu · Zheming Lu
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Three-Dimensional Model Analysis and Processing

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With 134 figures

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Preface

With the increasing popularization of the Internet, together with the rapid development of 3D scanning technologies and modeling tools, 3D model databases have become more and more common in fields such as biology, chemistry, archaeology and geography. People can distribute their own 3D works over the Internet, search and download 3D model data, and also carry out electronic trade over the Internet. However, some serious issues are related to this as follows: (1) How to efficiently transmit and store huge 3D model data with limited bandwidth and storage capacity; (2) How to prevent 3D works from being pirated and tampered with; (3) How to search for the desired 3D models in huge multimedia databases. This book is devoted to partially solving the above issues.

Compression is useful because it helps reduce the consumption of expensive resources, such as hard disk space and transmission bandwidth. On the downside, compressed data must be decompressed to be used, and this extra processing may be detrimental to some applications. 3D polygonal mesh (with geometry, color, normal vector and texture coordinate information), as a common surface representation, is now heavily used in various multimedia applications such as computer games, animations and simulation applications. To maintain a convincing level of realism, many applications require highly detailed mesh models. However, such complex models demand broad network bandwidth and much storage capacity to transmit and store. To address these problems, 3D mesh compression is essential for reducing the size of 3D model representation.

Feature extraction is a special form of dimensionality reduction. When the input data to an algorithm is too large to be processed and is suspected to be notoriously redundant (much data, but not much information), the input data will be transformed into a reduced representation set of features (also named a feature vector). If the features extracted are carefully chosen, it is expected that the features set will extract the relevant information from the input data, in order to perform the desired task using this reduced representation instead of the full size input. Feature extraction is an essential step in content-based 3D model retrieval systems. In general, the shape of the 3D object is described by a feature vector that serves as a search key in the database. If an unsuitable feature extraction method has been used, the whole retrieval system will be unusable. We must realize that 3D objects can be saved in many representations, such as polyhedral meshes, volumetric data and parametric or implicit equations. The method of feature extraction should accept this fact and it should be independent of data representation. The method should also be invariant under transforms such as translation, rotation and scale of the 3D object. Perhaps this is the most important requirement, because the 3D objects are usually saved in various poses and on various scales. The 3D object can be obtained either from a 3D graphics program or from a 3D input device. The second way is more susceptible to some errors, therefore the feature extraction method should also be insensitive to noise. Perhaps the last requirement is that it has to be quick to compute and easy to index. The database may contain thousands of objects, so the agility of the system would also be one of the main requirements.

Content-based visual information retrieval (CBVIR) is the application of computer vision to the visual information retrieval problem, which solves the problem of searching for digital images/videos/3D models in large databases. "Content-based" means that the search will analyze the actual contents of the visual media. The term "content" in this context might refer to colors, shapes, textures, or any other information that can be derived from the visual media itself. Without the ability to examine visual media content, searches must rely on metadata such as captions and keywords, which may be laborious or expensive to produce. A common characteristic of all applications in multimedia databases (and in particular in 3D object databases) is that a query searches for similar objects instead of performing an exact search, as in traditional relational databases. Multimedia objects cannot be meaningfully queried in the classical sense (exact search), because the probability that two multimedia objects are identical is very low, unless they are digital copies from the same source. Instead, a query in a multimedia database system usually requests a number of objects most similar to a given query object or to a manually entered query specification. Therefore, one of the most important tasks in a multimedia retrieval system is to implement effective and efficient similarity search algorithms. Typically, the multimedia data are modeled as objects in a metric or vector space, where a distance function must be defined to compute the similarity between two objects. Thus, the similarity search problem is reduced to a search for close objects in the metric or vector space. The primary goal in a 3D similarity search is to design algorithms with the ability to effectively and efficiently execute similarity queries in 3D databases. Effectiveness is related to the ability to retrieve similar 3D objects while holding back non-similar ones, and efficiency is related to the cost of the search, measured e.g., in CPU or I/O time. But, first of all one should define how the similarity between 3D objects is computed.

Digital watermarking is a branch of data hiding (or information hiding). It is the process of embedding information into a digital signal. The signal may be audios, pictures, videos or 3D models. If the signal is copied, then the information is also carried in the copy. An important application of invisible watermarking is in copyright protection systems, which are intended to prevent or deter unauthorized copying of digital media. Another important application is to authenticate the content of multimedia works, where fragile watermarks are commonly used for tamper detection (integrity proof). Steganography is an application of digital watermarking, where two parties communicate a secret message embedded in the digital signal. Annotation of digital photographs with descriptive information is another application of invisible watermarking. While some file formats for digital media can contain additional information called metadata, digital watermarking is distinct in that the data is carried in the signal itself.

Reversible data hiding is a technique that enables images or 3D models to be authenticated and then restored to their original forms by removing the watermark and replacing the images or 3D data which had been overwritten. This would make the images or 3D models acceptable for legal purposes. Although reversible data hiding was first introduced for digital images, it has also wide application scenarios for hiding data in 3D models. For example, suppose there is a column on a 3D mechanical model obtained by CAD. The diameter of this column is changed with a given data hiding scheme. In some applications, it is not enough that the hidden content is accurately extracted, because the remaining watermarked model is still distorted. Even if the column diameter is increased or decreased by 1 mm, it may cause a severe effect for this mechanical model cannot be well assembled with other mechanical accessories. Therefore, it also has significance in the design of reversible data hiding methods for 3D models.

Based on the above background, this book is devoted to processing and analysis techniques for 3D models, i.e., compression techniques, feature extraction and retrieval techniques and watermarking techniques for 3D models. This book focuses on three main areas in 3D model processing and analysis, i.e., compression, content-based retrieval and data hiding, which are designed to reduce redundancy in 3D model representations, to extract the features from 3D models and retrieve similar models to the query model based on feature matching, to protect the copyright of 3D models and to authenticate the content of 3D models or hide information in 3D models. This book consists of six chapters. Chapter 1 introduces the background to three urgent issues confronting multimedia, i.e., storage and transmission, protection and authentication, and retrieval and recognition. Then the concepts, descriptions and research directions for the newly-developed digital media, 3D models, are presented. Based on three aspects of the technical requirements, the basic concepts and the commonly-used techniques for multimedia compression, multimedia watermarking, multimedia retrieval and multimedia perceptual hashing are then summarized. Chapter 2 introduces the background, basic concepts and algorithm classification of 3D mesh compression techniques. Then we discuss some typical methods used in connectivity compression and geometry compression for 3D meshes respectively. Chapter 3 focuses on the techniques of feature extraction from 3D models. First, the background, basic concepts and algorithm classification related to 3D model feature extraction are introduced. Then, typical 3D model feature extraction methods are classified into six categories and are, discussed in eight sections, respectively. Chapter 4 discusses the steps and techniques related to content-based 3D model retrieval systems. First, we introduce the background, performance evaluation criteria, the basic framework, challenges and several important issues related to content-based 3D model retrieval systems. Then we analyze and discuss several topics for content-based 3D model retrieval, including preprocessing, feature extraction, similarity matching and query interface. Chapter 5 starts with the description of general requirements for 3D watermarking, as well as the classification of 3D model watermarking algorithms. Then some typical spatial domain 3D mesh model watermarking schemes, typical transform-domain 3D mesh model watermarking schemes and watermarking algorithms for other types of 3D models are discussed respectively. Chapter 6 starts by introducing the background and performance evaluation metrics of 3D model reversible data hiding. Then some basic reversible data hiding schemes for digital images are briefly reviewed. Finally, three kinds of 3D model reversible data hiding techniques are extensively introduced, i.e., spatial domain based, compressed domain based and transform domain based methods.

This book embodies the following characteristics. Firstly, it has novelty. The content of this book covers the research hotspots and their recent progress in the field of 3D model processing and analysis. For example, in Chapter 6, reversible data hiding in 3D models is a very new research branch. Secondly it has completeness. Techniques for every research direction are comprehensively introduced. For example, in Chapter 3, feature extraction methods for 3D models are classified and introduced in detail. Thirdly it is theoretical. This book embodies many theories related to 3D models, such as topology, transform coding, data compression, multi-resolution analysis, neural networks, vector quantization, 3D modeling, statistics, machine learning, watermarking, data hiding, and so on. For example, in Chapter 2, several definitions related to 3D topology and geometry are introduced in detail in order to easily understand the content of later chapters. Fourthly it is practical. For each application, experimental results for typical methods are illustrated in detail. For example, in Chapter 6, three examples of typical reversible data hiding are illustrated with detailed steps and elaborate experiments.

In this book, Chapters 1, 4 and 5 were written by Prof. Zheming Lu, Chapters 2 and 3 were written by Prof. Faxin Yu, Chapter 6 was written by Dr. Hao Luo with the aid of student Hua Chen. The whole book was finalized by Prof. Faxin Yu. The research results of this book are based on the accumulated work of the authors over a long period of time. We would like to show our great appreciation for the assistance of other teachers and students in the Institute of Astronautics and Electronic Engineering of Zhejiang University. The work was partially supported by the National Natural Science Foundation of China, the foundation from the Ministry of Education in China for persons showing special ability in the new century, and the foundation from the Ministry of Education in China for the best national Ph.D dissertations. Due to our limited knowledge, it is inevitable that errors and defects will appear in this book and we invite our readers to comment.

The authors
Hangzhou, China
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Contents

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Introduction

The digitization of multimedia data, such as images, graphics, speech, text, audio, video and 3D models, has made the storage of multimedia more and more convenient, and has simultaneously improved the efficiency and accuracy of information representation. With the increasing popularization of the Internet, multimedia communication has reached an unprecedented level of depth and broadness, and multimedia distribution is becoming more and more manifold. People can distribute their own works over the Internet, search and download multimedia data, and also carry out electronic trade over the Internet. However, some serious issues accompany this as follows: (1) How can we efficiently transmit and store huge multimedia information with limited bandwidth and storage capacity? (2) How can we prevent multimedia works from being pirated and tampered with? (3) How can we search for the desired multimedia content in huge multimedia databases?

1.1 Background

We first introduce the background to three urgent issues for multimedia, i.e., (1) storage and transmission, (2) protection and authentication, (3) retrieval and recognition.

1.1.1 Technical Development Course of Multimedia

"Multimedia" [1] is a compound word composed of "multiple" and "media", which means "multiple media". Here, "media" is the plural form of the word "medium". In fact, the word "medium" has two kinds of meaning in the computer field: one stands for the entities for storing information, such as diskettes, CDs, magnetic tapes and semiconductor memorizers; the other stands for the carriers for transmitting information, such as digits, characters, audio clips, graphics and images. Here, the word “media” in multimedia technology means the latter. “Monomedia” is one (word) as opposed to “multimedia” and, literally, multimedia is composed of several “monomedia”. People use various media during information communication, and multimedia is just the representation and transmission form for multiple information carriers. In other words, it is a technique to simultaneously acquire, process, edit, store and display more than two kinds of media, including text, audios, graphics, images, movies and videos, etc. In fact, it is the material development of computer and digital information processing technologies that enables people to process multimedia information and thus enables the realization of multimedia technology. Therefore, so-called “multimedia” stands no longer for multiple media themselves but for the whole series of techniques to deal with and apply them. In fact, “multimedia” has been viewed as a synonym of “multimedia technology”. It is worth noting that multimedia technology nowadays is often associated with computer technology. The reason is that the computer’s capability of digitization and interactive processing greatly promotes the development of multimedia technology. In general, people can view multimedia as the new technology or as product forming from the combination of advanced computer, video, audio and communication technologies.

The multimedia technique has been rapidly developed accompanied by the wide application of computer and network technologies, and computer network multimedia technology has become an area under rapid development and has gained research focus in the 21st century. As a rapidly developing all-round electronic information technology, multimedia technology has brought directional renovation to traditional computer systems and audio and video equipments, and will have a great effect on mass media. Since the mid to late 1980s, multimedia computer technology has become the focus of concern, and its definition is as follows: computers comprehensively process various kinds of multimedia information (text, graphics, images, audios and videos), which means various kinds of information is linked together to form a system with interactivity. Interactivity is one of the characteristics of multimedia computer technology, meaning the characteristic of interactive communication with users, which is the biggest difference from traditional media. Apart from providing users with solutions to problems on their own, such a change can help users learn and think with the aid of conversational communication and carry out systematical queries or statistical analysis in order to achieve the advancement of knowledge and the improvement of problem-solving ability. Multimedia computers will speed up the process of introducing computers to families and societies, and will bring a profound revolution to people’s work, life and entertainment. Since the 1990s, the progress that the world has made towards an information society has been significantly expedited, in which the application of multimedia technology has been playing a vital role. Multimedia improves a human’s information communication and shortens the communication path. The application of multimedia technology is a sign of the 1990s, and is a second revolution in the computer field.

On the whole, multimedia technology is nowadays developing in the following two directions.

One is networking, which means that, combined with wide-band network communication technology, multimedia technology enters areas such as scientific research, designing, enterprise management, office automation, remote education, telemedicine, retrieval, entertainment and automatic testing. In some recent films, we can often see a very personalized computer that can talk with humans and provide any information they want to know. It can play any music they want to listen to. If there is any accident anywhere in the world, it can report to them in time. It can monitor the status of all the apparatus at home, and can help to receive phone calls and remind humans what to do, and even transmit messages to their friends living far away. Today, because of the development of multimedia, all of the above dreams will come true.

The other direction is componentization together with intelligentization and embeddability of the multimedia terminal, which means improving the multimedia performance of computer systems to develop intelligent household appliances. The current household television system cannot be called a multimedia system, because although existing televisions also provide "sound, graphics, text" information, people can do nothing but select different channels, and people cannot interfere or change them but passively receive the programs from TV stations. This process is not two-way but one-way. However, we can forecast that, in the near future, the household television system will definitely be a multimedia system, which will combine many functions, such as entertainment, education, communication and consultation, all in one.

In summary, the birth of multimedia technology will definitely bring a revolution to the computer field once more. It indicates computers will not only be used in offices and laboratories but also be used in the household, in commerce, for travel, amusement, education and art, etc., i.e., in nearly all areas of daily life. At the same time, it means computers can be developed in the most ideal way for humans, i.e., with the integration of seeing and hearing, which completely plays down the human-computer interface.

1.1.2 Information Explosion

Real human civilization starts from the Internet. In fact, we are living with all kinds of networks, such as electrical networks, telephone networks, broadcast/television networks, commercial networks and traffic networks. However, all these networks are very different from the Internet, which has affected so many governments, enterprises and individuals in such a short time. Nowadays, the network has become a substitutable noun for the Internet. In the past few years, with the rapid development of computer and network techniques, the scale of the Internet has been suddenly expanded. The Internet technique breaks the traditional borderline, which makes the world smaller and smaller, while making the market larger and larger. The wide world is like a global village, where the global economy and information networking promote and depend on each other. The Internet makes the speed and scale of information acquisition and transmission reach an unprecedented level. In the era of information networking, the Internet should be considered for any product or technique. Network information systems are playing more and more important roles in politics, military affairs, finance, commerce, transportation, telecommunication, culture and education. Modern communication and transmission techniques have greatly improved the speed and extent of information transmission. The technical means include broadcasts, television, satellite communication and computer communication using microwave and optical fiber communication networks, which overcome traditional obstacles in space and time and further unite the whole world. However, the accompanying issues and side effects are as follows: A surge of information overwhelms people, and it is very hard to retrieve accurately and rapidly the information most needed from the tremendous amount of information. This phenomenon is called the information explosion [2], also called "information overload" or "knowledge bombing".

The information explosion describes the rapid development in the amount of information or human knowledge in recent years, whose speed is like a bomb engulfing all the world. With regard to the phrase "information explosion", it can date back to the 1980s. At that time, besides broadcasting, television, telephone, newspapers and various publications, new means of communication, i.e., computers and communication satellites emerged, making the amount of information increase suddenly like an explosion. Statistics show that over the past decade the amount of information all over the world doubled every 20 months. During the 1990s, the amount of information continued to increase dramatically. At the end of the 1990s, due to the emergence of the Internet, information distribution and transmission got out of control, and a great deal of false or useless information was generated, resulting in the pollution of information environments and the birth of "waste messages". Because everyone can freely air his opinion over the Internet, and the distribution cost can be ignored, in a sense everyone can become an information manufacturer on the global level, and thus information really starts to explode. As times go by, the information explosion manifests itself mainly in five aspects：(1) the rapid increase in the amount of news; (2) the dramatic increase in the amount of amusement information; (3) a barrage of advertisements; (4) the rapid increase in scientific and technical information; (5) the overloading of our personal receptiveness. However, faced with the inflated amount of information and the enormous pressure of "chaotic information space" and "information surplus", people out of the blue become hesitant in their urgent pursuit and expectation of information. Even if we take 24 hours every day to read information, we cannot take it all in, and besides, there is a great deal of useless or false information. Useful information can increase economic benefits and promote the development of human society, but if the information increases in a disorderly fashion and even runs out of control, it will bring about various social problems such as information crime and information pollution. People on the one hand are enjoying the convenience brought about by abundant information over the Internet; on the other hand they are suffering from annoyance due to the "information explosion". "Information explosion" has had a negative effect on the advance of the social economy. A recent survey of ten multinational corporations has revealed that, because they have to deal with a great deal of information that exceeds their ability to analyse it, their efficiency in decision-making is severely disturbed, even resulting in wrong decisions or difficulty in making the optimal decision. On detailed analysis, nowadays collecting information has cost us much more than the intrinsic value of that information. At present, besides an abundance of useful information, there is also a great deal of pornographic content, violent content and false advertising over the Internet. These junk messages have deluged us, to become a new public nuisance, just like the pollution produced by industrial waste, medical and other human refuse, and they have confused users in their rapid search for useful information.

The opposite of "information explosion" is "information shortage". On the one hand, from the quantitative angle, an information explosion refers to the phenomenon where web information increases exponentially because of the advance in transmission techniques and the openness of the transmission environment, while information shortage refers to a situation where the amount of information cannot satisfy the receiver's needs, because of congestion in the channels or a lack of information sources. In this sense, information shortage is a kind of absolute shortage. On the other hand, from the qualitative angle, accompanied by the information explosion, the really valuable information is submerged by a great deal of waste messages, and the receivers are thrown into great confusion because of numerous and jumbled items of information. In this sense, information shortage is a kind of relative shortage.

Nowadays people are devoting themselves to solving the "information explosion" problem from two aspects, i.e., technology and management. From the point of view of management, all governments have promulgated corresponding regulations and byelaws for network information. However, it is hard to have a unified worldwide standard due to the differences in constitutions, ideologies, conventions and moral values from country to country. Therefore, it is impractical to create a single regulation to control "waste messages" for worldwide webs. From such cognition, people try to seek technical solutions. Since the 1990s, every country has laid heavy stress on databases, data mining and information standardization technologies, resulting in the emergence of a new interdisciplinary field, knowledge discovery. Currently, the main technologies for obtaining information are retrieval technologies, e.g., search engines based on cataloguing, keywords-based search engines and content-based retrieval systems. In addition, some internet content providers (ICPs) push the special information to users through an intelligent proxy server according to users' customization, which is called the push service.

Based on the background to the information explosion era, this book focuses on applying retrieval technology to deal with the information explosion problem with regard to the new kind of media, 3D models, in Chapter 4. Apart from information retrieval, another effective technical solution to the information explosion is data compression technology. As is well known, the amount of digitalized information is huge, which brings extreme pressure to the storage capacity of memorizers, the transmission bandwidth of channels and the processing speed of computers. With regard to this problem, it is impractical to purely increase the storage capacity, the bandwidth or the CPU speed. If we adopt advanced compression algorithms to compress the digitalized audiovisual data, we can not only save the storage space but also make it possible for the computer to process and play the audiovisual information in a real-time manner. This book will focus on the 3D model compression problem in Chapter 2.

1.1.3 Network Information Security

People neglect the security problems of most modern computer networks at the beginning of construction and, even if they do not, they only base the security mechanism on the physical security. Therefore, with the enlargement of the networking scale, this physical security mechanism is but an empty shell in the network environment. In addition, the protocol in use nowadays, e.g., the TCP/IP protocol, does not take the security problem into account at the beginning. Thus, openness and resource sharing are the main rootstock of the computer networking security problem, and the security mainly depends on encryption, network user authentication and access control strategies. Facing such severe threats that harm network information systems and considering the importance of network security and secrecy, we must take effective measures in order to guarantee the security and secrecy of the network information. The network measures for security can be classified in the following three categories: logical-based, physical-based and policy-based. In the face of various threats that harm computer networking security more and more severely, only using physical-based or policy-based means cannot effectively keep away computer-based crime. People should therefore adopt logical-based measures, that is to research and develop effective techniques for network and information security. Even if we have very self-contained policies and rules for security and secrecy, very advanced techniques for security and secrecy and flawless physical security mechanisms, all efforts will go to waste if the above knowledge cannot be popularized.

People's understanding of information security is continually updated. In the era of host computers, people understand information security as the protection of confidentiality, integrality and availability of information, which is data-oriented. In the era of microcomputers and local networks in the 1980s, because of the simple structure of users and networks, information security was administrator-oriented and stipulation-oriented. In the era of the Internet in the 1990s, every user could access, use and control the connected computers everywhere, and thus information security over the Internet emphasizes connection-oriented and user-oriented security. Thus it can be seen that data-oriented security considers the confidentiality, integrality and availability of information, while user-oriented security considers authentication, authorization, access control, non-repudiation and serviceability, together with content-based individual privacy and copyright protection. Combining the above two aspects of security, we can obtain the generalized information security [3] concept, that is all theories and techniques related to information security, integrality, availability, authenticity and controllability, suming up physical security, network security, data security, information content security, information infrastructure security and public information security. On the other hand, information security in the narrow sense indicates information content security, which is the protection of the secrecy, authenticity and integrality of the information, avoiding attackers' wiretapping, imitating, beguilement and embezzlement and protecting the legal users' benefits and privacy. The secure service issues in the information security architecture rely on ciphers, digital signatures, authentication techniques, firewalls, secure audit, disaster recovery, anti-virus, preventing hacker intrusion, and so on. Among them, cryptographic techniques and management means are the core of information security, while the security standards and system evaluation methods are the bases of information security. Technically, information security is a marginal integrated subject involving computer science, network techniques, communication techniques, applied mathematics, number theory, information theory, and so on.

Network information security consists of four aspects, i.e., the security problems in information communication and storage, and the audit of network information content and authentication. To maintain the security of data transmission, it is necessary to apply data encryption and integrity identification techniques. To guarantee the security of information storage, it is necessary to guarantee the database security and terminal security. An information content audit checks the content of the input and output information from networks, so as to prevent or trace possible whistle-blowing. User identification is the process of verifying the principal part in the network. Usually there are three kinds of methods for verifying the principal part identity. One is that only the secret known by the principal part is available, e.g., passwords or keys. The second is that the objects carried by the principal part are available, e.g., intelligent cards or token cards. The third is that only the principal part's unique characteristics or abilities are available, e.g., fingerprints, voices, retina, signatures, etc. The technical characteristics of network information security mainly embody the following five aspects: (1) Integrity. It means the network information cannot be altered without authority. It is against active attacks, guaranteeing data consistence and preventing data from being modified and destroyed by illegal users. (2) Confidentiality. It is the characteristic that the network information cannot be leaked to unauthorized users. It is against passive attacks so as to guarantee that the secret information cannot be leaked to illegal users. (3) Availability. It is the characteristic that the network information can be visited and used by legal users if needed. It is used to prevent information and resource usage by legal users from being rejected irrationally. (4) Non-repudiation. It means all participants in the network cannot deny or disavow the completed operations and promises. The sender cannot deny the already sent information, while the receiver also cannot deny the already received information. (5) Controllability. It is the ability to control the content of network information and its prevalence. Namely, it can monitor the security of network information.

The coming of the network information era also proposes a new challenge to copyright protection. Copyright is also called author's rights. It is a general designation of legal rights based on a special production and the economic rights which completely dominate this production and its interest. With the continuous enlargement of the network scope and the gradual maturation of digitalization techniques, the quantity of various digitalized books, magazines, pictures, photos, music, songs and video products has increased rapidly. These digitalized products and services can be transmitted by the network without the limitation of time or space, even without logistic transmission. After the trade and payment are completed, they can be efficiently and quickly provided for clients by the network. On the other hand, openness and resource sharing of the network will cause the problem of how to validly protect the digitalized network products' copyright. There must be some efficient techniques and approaches for the prevention of digitalized products from altering, counterfeiting, plagiarizing and embezzling, etc.

Information security protection methods are also called security mechanisms. All security mechanisms are designed for some types of security attack threats. They can be used individually or in combination according to different manners. Commonly used network security mechanisms are as follows. (1) Information encryption and hiding mechanism. Encryption makes an attacker unable to understand the message content and thus information is protected, while hiding conceals the useful information in other information, and thus the attacker cannot find it. It not only realizes information secrecy, but also protects the communication itself. So far, information encryption is still the most basic approach in information security protection, while information hiding is a new direction in information security areas. It draws more and more attention in the applications of digitalized productions' copyright protection. (2) Integrity protection. It is used for the prevention of illegal alteration based on cipher theory. Another purpose of integrity protection is to provide non-repudiation services. When information source's integrity can be verified but cannot be simulated, the information receiver can verify the information sender. Digital signatures can provide methods for us. (3) Authentication mechanism. This is the basic mechanism of network security, namely that network instruments should authenticate each other so as to guarantee the right operations and audit of a legal user. (4) Audit. It is the foundation for preventing inner criminal offenses and for taking evidence after accidents. Through the records of some important events, errors can be localized and reasons for successful attacks can be found when mistakes appear in the system or the system is attacked. Audit information should prevent illegal deletion and modification. (5) Power control and access control. It is the requisite security means of host computer systems. Namely, the system endows suitable operation power to a certain user according to the right authentication, and thus makes him not exceed his authority. Generally, this mechanism adopts the role management method. That is, aiming at system requirements, it defines various roles, e.g., manager, accountant, etc., and then endows them with different executive powers. (6) Traffic padding. It generates spurious communications or data units to disguise the amount of real data units being sent. Typically, useless random data are sent out in a vacancy and thus enhance the difficulty of obtaining information through the communication stream. Meanwhile, it also enhances the difficulty of deciphering the secret communications. The sent random data should have good simulation performance, and thus can mix the false with the genuine. This book focuses on applying digital watermarking techniques to solve copyright protection and content authentication problems for 3D models, involving the first three security mechanisms.

1.1.4 Technical Requirements of 3D Models

Before the emergence of 3D models, multimedia technology experienced three waves: digital sound in the 1970s, digital images in the 1980s and digital videos in the 1990s. Human visual perception possesses the 3D stereo property. 3D models and their corresponding 3D scenes can therefore afford more abundant visual perceptual details than 2D images. With the development of 3D data acquisition, 3D graphics modeling and graphics hardware technologies, people have generated more and more 3D object databases for virtual reality, 3D games and industrial solid CAD models, and so on. Here, CAD, i.e., Computer Aided Design, means that designers carry out the design work with the aid of computers and their graphics devices. With the increasing popularization of 3D scanning technologies and 3D modeling tools, 3D model databases have become more and more common in fields such as biology, chemistry, archaeology and geography. On the other hand, the dilatation of the Internet has enhanced the ability to retrieve 3D models that are dispersedly stored, and has created favorable conditions to efficiently transmit high-quality 3D models. Currently, 3D models have been applied to various fields: In the medical field, 3D models are used to accurately describe the organs; in the movie industry, 3D models are utilized to represent the characters, objects and scenes; in the video game industry, 3D models are adopted as the game sources in computers and video games; in the science field, 3D models can be used to show accurate structures of compounds; in the architecture industry, they are used to display the buildings and landscapes; in the engineering field, they are used to design new devices, vehicles, structures, and so on; in the geosciences, people start to construct 3D geologic models.

3D models have been the fourth generation of multimedia data type following audios, images and videos, and the increasingly developing Internet and function-enhanced computers have provided conditions for 3D model processing and sharing. Thus, in the near future people can freely use 3D models just like 2D images. The former problem of "how to acquire 3D models" has been changed into the current problem of "how to search for 3D models we need", which has resulted in the increasing need for 3D model retrieval technologies. For example, it is a long laborious process to carry out high-fidelity 3D modeling. If there are some former models that can be reused, the cost will be greatly reduced. At the same time, the research results of content-based 3D model retrieval techniques can be widely applied to fields such as virtual geographical environments, CAD, molecular biology, military affairs, medicine, chemistry, archaeology and industrial manufacturing, and one can also find applications in electronic business and web-based search engines. Therefore, how to rapidly search for the required 3D models has been a second popular topic following the retrieval techniques for texts, audios, images and videos. The 3D model retrieval technology involves several areas such as artificial intelligence, computer vision and pattern recognition. The underlying problem in content-based 3D model retrieval systems is to select appropriate features to distinguish dissimilar shapes and index 3D models. Based on these requirements, this book discusses 3D model feature extraction techniques in Chapter 3, and introduces 3D model retrieval techniques in Chapter 4.

On the other hand, with the ceaseless emergence of advanced modeling tools and the increasing maturation of 3D shape data scanning techniques, people have put forward greater requests for accuracy and details of 3D geometric data, which has at the same time brought about a rapid growth in the scale and complexity of 3D geometric data. Huge geometric data have enormously challenged the capacity and speed of current 3D graphics search engines. Furthermore, the development of the Internet makes the application of 3D geometric data broader and broader. However, the limitation of bandwidth has severely restricted the distribution of this kind of media. It is not sufficient to solve this problem merely based on the increase in the contribution of hardware devices, but we also need to research 3D model compression techniques. Thus, this book discusses 3D model compression techniques in Chapter 2.

More severely, with the development of computer technologies, CAD, virtual reality and network technologies have made considerable progress, and more and more 3D models have been created, distributed, downloaded and used. Because 3D models possess commercial value, visual value and economic benefits, the producers and copyright owners of these 3D products will inevitably have to face up to the practical issues of copyright (or intellectual property rights) protection and content authentication during the distribution of 3D models over the Internet. Thus, this book discusses the watermarking and reversible data hiding techniques of 3D models in Chapters 5 and 6.

Besides the above three technical requirements, there are some other technical requirements for 3D models including simplification, reconstruction, segmentation, interactive display, matching and recognition, and so on. For example, computer- aided geometric modeling techniques have been widely used during product development and manufacturing processes, but there are still many products not originally described by CAD models because the designers or manufacturers are faced with material objects. In order to utilize the advanced manufacturing technology, we should transform material objects into CAD models, and this has been a relatively independent research area in CAD or CAM (computer-aided manufacturing) systems, i.e., reverse engineering [4]. To take a second example, mesh segmentation [5] has become a hot research topic because it has become an important technical requirement to modify current models according to the new design goal by reusing previous models. Mesh segmentation stands for the technique of segmenting a closed mesh polyhedron or orientable 2D manifold, according to certain geometric or topological characteristics, into a certain number of sub-meshes with simple shapes, each sub-mesh self-connected. This work has been widely applied in research works on digital geometric processing such as mesh reconstruction based on 3D point cloud data, mesh simplification, levels of detail (LOD) modeling, geometric compression and transmission, interactive editor, texture mapping, mesh tessellation, geometry deformation, parameterization of local areas and spline surface reconstruction in reverse engineering.

1.2 Concepts and Descriptions of 3D Models

In the following, the concepts, descriptions and research directions for newly-developed digital media, 3D models, are presented. Based on three aspects of technical requirements, the basic concepts and the commonly-used techniques for multimedia compression, multimedia watermarking, multimedia retrieval and multimedia perceptual hashing are then summarized.

1.2.1 3D Models

A model is the abstract representation of an objective, including structures, attributes, variation laws and relationships among components. 3D models are the fourth generation of multimedia following sound, images and videos. A 3D model represents a 3D object using a collection of points in the 3D space, connected by various geometric entities such as triangles, lines, curved surfaces, etc. A typical example is shown in Fig. 1.1. Being a collection of data (points and other information), 3D models can be created by hand, algorithmically (procedural modeling), or scanned. 3D models have been widely used anywhere in 3D graphics. Actually, their use predates the widespread use of 3D graphics on personal computers. Many computer games use pre-rendered images of 3D models as sprites before computers can render them in real-time. Today, 3D models are used in a wide variety of fields. The medical industry uses detailed models of organs. The movie industry uses them as characters and objects for animated and real-life motion pictures. The video game industry uses them as assets for computer and video games. The science sector uses them as highly detailed models of chemical compounds. The architecture industry uses them to demonstrate proposed buildings and landscapes through software architectural models. The engineering community uses them as designs of new devices, vehicles and structures, as well as for a host of other uses. In recent decades, the earth science community has started to construct 3D geological models as a standard practice.

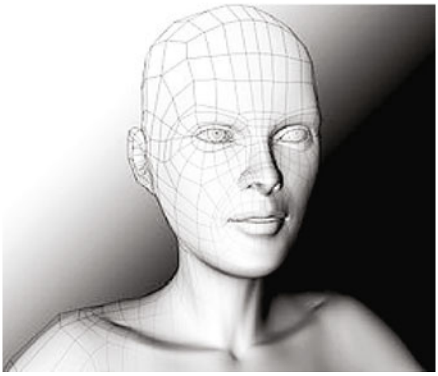

Fig. 1.1. A typical polygon mesh model

3D models can be roughly classified into two categories: (1) Solid models. These models define the volume of the object they represent (like a rock). These are more realistic, but more difficult to build. Solid models are mostly used for non-visual simulations such as medical and engineering simulations, and for CAD and specialized visual applications such as ray tracing and constructive solid geometry. (2) Shell/Boundary models. These models represent the surface, e.g., the boundary of the object, not its volume (like an infinitesimally thin eggshell). These are easier to work with than solid models. Almost all visual models used in games and films are shell models.

Because the appearance of an object depends largely on the exterior of the object, boundary representations are common in computer graphics. 2D surfaces are a good analogy for the objects used in graphics, though quite often these objects are non-manifold. Since surfaces are not finite, a discrete digital approximation is required: polygonal meshes are by far the most common representations, although point-based representations have been gaining some popularity in recent years. Level sets are a useful representation for deforming surfaces which undergo many topological changes, such as fluids.

The process of transforming representations of objects, such as the middle point coordinate of a sphere and a point on its circumference into a polygon representation of a sphere, is called tessellation. This step is used in polygon-based rendering, where objects are broken down from abstract representations ("primitives") such as spheres, cones, etc., to so-called meshes, which are nets of interconnected triangles. Meshes of triangles (instead of e.g. squares) are popular as they have proven to be easy to render using scan line rendering. Polygon representations are not used in all rendering techniques, and in these cases the tessellation step is not included in the transition from abstract representation to the rendered scene.

There are two types of information in a 3D model, geometrical information and topological information. Geometrical information generally represents shapes, locations and sizes in the Euclidean space, while topological information stands for the connectivity between different parts of the 3D model. The 3D model itself is invisible, but we can perform the rendering operation at different levels of detail based on simple wireframes or shading based on different methods. Here, rendering is the process of generating an image from a model by computer programs. The model is a description of 3D objects in a strictly defined language or data structure. It may contain geometry, viewpoint, texture, lighting and shading information. The generated image is a digital image or raster graphics image. This term may be analogous with an “artist’s rendering” of a scene. Rendering is also used to describe the process of calculating effects in a video editing file to produce the final video output. Shading is a process in drawing for depicting levels of darkness on paper by applying media more densely or with a darker shade for darker areas, and less densely or with a lighter shade for lighter areas. In computer graphics, shading refers to the process of altering a color according to its angle to lights and its distance from lights to create a photorealistic effect. Shading is performed during the rendering process. However, a lot of 3D models are covered with texture, and we call this process texture mapping. It is a method for adding detail, surface texture, or color to a computer-generated graphic or 3D model. Its application to 3D graphics was pioneered by Dr. Edwin Catmull in his Ph.D thesis in 1974. A texture map is applied (mapped) to the surface of a shape or polygon. This process is akin to applying patterned paper to a plain white box. The way by which the resulting pixels on the screen are calculated from the texels (texture pixels) is governed by texture filtering. The fastest method is to use the nearest-neighbor interpolation technique, while bilinear interpolation and trilinear interpolation between mipmaps are two commonly used alternatives which reduce aliasing or jaggies. In the event of a texture coordinate being outside the texture, it is either clamped or wrapped.

1.2.2 3D Modeling Schemes

When we use computers to analyze and research objective things, it is essential to adopt suitable models to represent the actual objects or abstract phenomena. This process is called modeling. In 3D computer graphics, 3D modeling [6] is the process of developing a mathematical, wireframe representation of any 3D object (either inanimate or living) via specialized software. It can be displayed as a 2D image through a process called 3D rendering or used in a computer simulation of physical phenomena. The model can also be physically created using 3D printing devices. Models may be created automatically or manually. The manual modeling process of preparing geometric data for 3D computer graphics is similar to plastic arts such as sculpting. 3D modeling has played an important role in architecture, medical imaging, cultural relic preservation, 3D animation, 3D games, film’s technical razzle-dazzle making, and so on.

3D scanners and image acquisition systems are rapidly becoming more affordable and allow the building of highly accurate models of real 3D objects in a cost- and time-effective manner. To construct 3D models for actual objects, we must first acquire related attributes of samples, such as geometrical shapes and surface textures. The data that record such information are called 3D data, and 3D data acquisition is the process by which the 3D information is acquired from samples and organized as the representation consistent with the samples' structures. The methods of acquiring 3D information from samples can be classified in the following five categories:

(1) Methods based on direct design or measurement. They are often used in early architecture 3D modeling. They utilize engineering drawing to obtain the three views of each model.

(2) Image-based methods. They construct 3D models based on pictures. They first obtain geometrical and texture information simultaneously by taking photos, and then construct 3D models based on obtained images.

(3) Mechanical-probe-based methods. They acquire the surface data by physical touch between the probe and the object. They require that the object hold a certain hardness.

(4) Methods based on volume data restoration. They adopt a series of slicing images of the object to restore the 3D shape of the object. They are often used in medical departments with X-ray slicing images, CT images and MRT images.

(5) Region-scanning-based methods. They obtain the position of each vertex in the space by estimating the distance between the measuring instrument and each point on the object surface. Two examples of the methods are optical triangulation and interferometry.

The main problem in 3D modeling is to render 3D models based on 3D data. To achieve a better visual effect, we should guarantee it has smooth surfaces, without burrs and holes, and make 3D models embody a third dimension and sense of reality. At the same time, we should organize the data in a better manner to reduce the storage space and speed up the displaying. Current modeling techniques can be mainly classified in three categories: geometric-modeling-based, 3D scanner-based and image-based, which can be described in detail as follows.

1.2.2.1 Geometric-Modeling-Based Techniques

Geometric modeling is a branch of applied mathematics and computational geometry that studies methods and algorithms for the mathematical description of shapes. The shapes studied in geometric modeling are mostly 2D or 3D, although many of its tools and principles can be applied to sets of any finite dimension. Today most geometric modeling processes are done with computers and for computer-based applications. 2D models are important in computer typography and technical drawing. 3D models are central to CAD/CAM, and widely used in many applied technical fields such as civil and mechanical engineering, architecture, geology and medical image processing. Geometric models are usually distinguished from procedural and object-oriented models, which define the shape implicitly by an opaque algorithm that generates its appearance. They are also contrasted with digital images and volumetric models which represent the shape as a subset of a fine regular partition of space, and with fractal models that give an infinitely recursive definition of the shape. However, these distinctions are