

ADVANCED TOPICS IN SCIENCE AND TECHNOLOGY IN CHINA

Weidong Geng

# The Algorithms and Principles of Non-photorealistic Graphics

Artistic Rendering and  
Cartoon Animation



ZHEJIANG UNIVERSITY PRESS  
浙江大学出版社



Springer

Weidong Geng

# The Algorithms and Principles of Non-photorealistic Graphics

Artistic Rendering and Cartoon Animation

With 314 figures, mostly in color



ZHEJIANG UNIVERSITY PRESS  
浙江大学出版社



Springer

## 图书在版编目 (CIP) 数据

艺术化绘制的图形学原理与方法 = The Algorithms and Principles of Non-photorealistic Graphics; Artistic Rendering and Cartoon Animation: 英文 / 耿卫东著. — 杭州: 浙江大学出版社, 2010. 1

(中国科技进展丛书)

ISBN 978-7-308-06600-6

I. 艺… II. 耿… III. 计算机图形学—英文 IV. TP391.41

中国版本图书馆 CIP 数据核字 (2009) 第 159896 号

Not for sale outside Mainland of China  
此书仅限中国大陆地区销售

## 艺术化绘制的图形学原理与方法

耿卫东 著

---

责任编辑	许佳颖
封面设计	Frido Steinen-Broo
出版发行	浙江大学出版社
	网址: <a href="http://www.zjupress.com">http://www.zjupress.com</a>
	Springer-Verlag GmbH
	网址: <a href="http://www.springer.com">http://www.springer.com</a>
排 版	杭州理想广告有限公司
印 刷	浙江印刷集团有限公司
开 本	787mm×960mm 1/16
印 张	23.25
字 数	575 千
版 次	2010 年 1 月第 1 版 2010 年 1 月第 1 次印刷
书 号	ISBN 978-7-308-06600-6 (浙江大学出版社)
	ISBN 978-3-642-04890-6 (Springer-Verlag GmbH)
定 价	160.00 元

---

版权所有 翻印必究 印装差错 负责调换

浙江大学出版社发行部邮购电话 (0571)88925591

---

## Preface

Non-photorealistic computer graphics is a multidisciplinary field in the research community, involving computer arts, computer graphics, computer vision, digital image/video processing and visual cognitive psychology. It aims at the computer generation of images and animations that are made in part “by hand” in appearance, and are characterized by their use of randomness, abstraction, ambiguity, or arbitrariness rather than completeness and adherence to the portrayed objects’ properties. In essence, it mimics the eyes and minds of artists and designers to create, view and depict the graphics world, effectively carrying-out the visual communication between computers and human beings.

### Coverage and Audience

This book mainly focuses on the following five core issues in non-photorealistic computer graphics.

- (1) How to create the paintings, artworks or sculptures from a digitized blank canvas or a standard shape with the tools simulated by the computer.
- (2) How to convert a series of reference images into the resultant depiction with the desired visual effect.
- (3) How to automatically generate the artistic rendition or technical illustrations from the 3D models in terms of the stylized parameters.
- (4) How to produce the comprehensive and expressive visualizations from a set of graphical and textual information on the basis of the semantic meanings to be conveyed.
- (5) How to speed up the production of cartoon animation by computer-assisted refinement of traditional pipeline and the exploration of novel approaches.

The author not only take a survey of the state-of-the-art research as well as trends and open-ended questions regarding the aforementioned five

core issues, but also discuss the theoretical underpinnings of the field. This includes detailing a host of useful algorithms and addressing two applications of particular interest: artistic rendering and cartoon animation.

The book will be useful to practitioners in the field. It contains a wealth of examples, particularly in the form of images, which the author hope will motivate the reader in the use of non-photorealistic computer graphics. The methods introduced are explained in enough detail so that programs can be written directly without a major conceptual effort.

Another use of the book is for reference by researchers in the field. The bibliographic references at the end of the chapters give the necessary pointers to the important publications. In the case of researchers in the field of non-photorealistic computer graphics, the methods that are built up are referenced appropriately, and a comprehensive index aids in selective readings.

## Objective

Non-photorealistic computer graphics is a relatively young field, and new works are constantly being published. The intent of this book is to bring together a coherent conceptual framework for all of the research to date in the context of computer graphics, art history and theory, and cognitive psychology.

Although the field of non-photorealistic rendering has existed for more than two decades, it has for a long time not been taken seriously by large parts of the research community. The area has thus far been unstructured, making it increasingly difficult to identify and assess new open problems. Indeed, sometimes papers have even “reinvented the wheel,” albeit in a different context and application concern. Recent years have seen many algorithms, papers, and software tools devoted to artistic rendering and computer-assisted cartoon animation. The time has become ripe for a systematic assessment of the literature. The following are our goals:

- (1) To become the seminal reference for core issues surrounding artistic rendering and cartoon animation.
- (2) To describe and review state-of-the-art advances in the field of non-photorealistic computer graphics, and to distill the breadth of cutting-edge non-photorealistic modeling, rendering and animation technologies into a coherent, accessible treatise.
- (3) To provide the guidelines for researchers and software developers to assess and implement the best solution for their interactive arts application.

## Acknowledgement

I would like to thank my family for their love, support, and patience, and a few of the great many people for their instrumental contributions in taking

this book from an initial suggestion to a final product. I express my gratitude to Prof. Yunhe Pan, fellow of Chinese Academy of Engineering, for his time reviewing this book and contributing his many deep insights into the topic in the final chapter of the book.

A number of colleagues in the State Key Lab of CAD & CG at Zhejiang University gave the author support, offered constructive criticisms, or provided illustrations to include in the book. These include Profs. Hujun Bao, Yueting Zhuang, Dongming Lu, and Duanqing Xu. I am also indebted to the graduate students, faculty, and researchers in the research group of Computer Animation and Perception at Zhejiang University.

I wishes to thank those persons who provided the support to make this book appear, including the administrative, technical, and secretarial staff in our college who kept things up and running, even under adverse workloads (Ms Qi Shen, Ms Xuefang Zhang, etc.). I also thanks the graduate students at Zhejiang University who studied the topic with previous versions of the manuscript, and all of the colleagues and peers around the world who did great research and gave me the copyrights of their images.

The continuous research and development on non-photorealistic computer graphics in the past years were supported by the following grants: National Natural Science Foundation of China (Grant Nos.: 6960302, 69973044, 60373032, 60773183 and 60633070), National High Technology Research and Development Program of China (Grant Nos.: 2006AA01Z313 and 2006AA01Z335), New Century Excellent Talents in University (NCET-07-0743), and Program for Changjiang Scholars and Innovative Research Team in University (PCSIRT0652).

Finally, I also acknowledges the prodigious work of the people at Zhejiang University Press and Springer.

*Weidong Geng*  
Hangzhou, China  
August 16, 2009

---

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	The Brief History: from Photorealism to Non-photorealism	1
1.2	What is Non-photorealistic Computer Graphics	2
1.2.1	Image, Picture, and Visualization	3
1.2.2	Photorealistic versus Non-photorealistic Rendering	4
1.3	The Framework for Non-photorealistic Computer Graphics	6
	References	9
<b>2</b>	<b>Simulating Artistic Media for Digitized Creation of Artworks</b>	<b>11</b>
2.1	Stroke-based Artistic Drawing	11
2.1.1	Interactive Drawing Based on Brushstrokes	11
2.1.2	Pen-and-ink Illustration by Stroke Textures	15
2.1.3	Interactive Pencil Drawing	18
2.1.4	Simulating Wax Crayons	26
2.2	Oriental Calligraphy and Black Ink Painting	30
2.2.1	Modeling of Soft Brushes	31
2.2.2	Calligraphy with Soft Brushes	39
2.2.3	Oriental Black Ink Painting	43
2.3	Simulation of a Colored Painting	54
2.3.1	The Computational Model of Rendering Colored Pigments	55
2.3.2	Simulation of Watercolor Painting	58
2.3.3	Simulation of Oil Painting	68
2.4	Digitized Sculpting	77
2.4.1	Digitized Wood Sculpting	78
2.4.2	Digitized Metal Embossing	81
2.5	Creation of Artwork in a Virtual Environment	83
2.6	Summary	86
	References	87

<b>3</b>	<b>Computer-aided Design of Art Patterns</b>	91
3.1	The Overview of Art Pattern Design	92
3.2	Art Pattern Creation by Fractals	94
3.3	Art Pattern Creation by Shape Grammars	96
3.4	Layout-based Creation of Art Patterns	100
3.4.1	Novel Layout Creation Based on Regular Structures	100
3.4.2	Layout Creation Integrated with Fabrication Craft	103
3.4.3	Art Pattern Creation by Stylized Layout	104
3.5	Knowledge-based Creation of Art Patterns	106
3.5.1	Aesthetical Knowledge Representation for Art Pattern Generation	107
3.5.2	Generation of Art Patterns by Synthesis Reasoning	108
3.6	Summary	111
	References	111
<b>4</b>	<b>Artistic Painting by Reference Images</b>	113
4.1	Artistic Effect Generation by Pixel-level Image Processing	113
4.1.1	Artistic Processing via Digital Half-toning	114
4.1.2	Artistic Processing with Heuristic Rules	115
4.2	Converting Images into Artistic Painting by Strokes	118
4.2.1	Image-based Stippling Drawing	120
4.2.2	Image-based Mosaic and Stained Glass Simulation	124
4.2.3	Image-based Pen-and-ink Illustration	127
4.2.4	Image-based Pencil Drawing	131
4.2.5	Image-based Oriental Painting	137
4.2.6	Image-based Colored Painting	138
4.3	Artistic Transfer of Color and Texture from Reference Images	145
4.3.1	Artistic Transfer of Color	146
4.3.2	Artistic Transfer of Texture	149
4.4	Image-based Painting Driven by Examples	152
4.4.1	Painting Style Simulation by Image Analogy	153
4.4.2	Artistic Painting Generation by Stroke Templates from Examples	155
4.5	Summary	157
	References	158
<b>5</b>	<b>Artistic Rendering for 3D Object</b>	161
5.1	Artistic Rendering Based on Traditional 3D Rendering Pipeline	162
5.1.1	Non-photorealistic Lighting Model	162
5.1.2	Non-realistic Projection	168
5.1.3	Non-photorealistic Texture Mapping and Synthesis	174
5.2	Non-photorealistic Rendering with Interim Images	179
5.2.1	Pen-and-ink Illustration from 3D Object	180



5.2.2	Pencil Drawing from 3D Polygonal Object .....	185
5.2.3	Chinese Painting from 3D Model .....	187
5.2.4	Colorful Painting from 3D Model .....	191
5.3	Artistic Silhouette and Line-drawing for 3D Model .....	192
5.3.1	Silhouette Rendering from 3D Polygonal Object .....	192
5.3.2	Line-drawing for 3D Surface .....	198
5.4	Artistic Rendering for 3D Landscape .....	201
5.4.1	Artistic Simulation by Placing Artistic Particles and Strokes on the 3D Surface .....	202
5.4.2	Artistic Rendering of Plants Based on Their 3D Structure .....	204
5.4.3	Artistic Rendition for Point-based Models .....	209
5.5	Artistic Illustration of Volume-based Models .....	212
5.5.1	Artistic Rendering of Surface Features of Volume Model .....	213
5.5.2	Artistic Illustration of Internal Structure of Volume Model .....	217
5.6	Summary .....	223
	References .....	224
<b>6</b>	<b>Expressive Rendering .....</b>	<b>229</b>
6.1	Comprehensible Rendering .....	230
6.1.1	Enhancement of Rendering by Emphasis of Visual Cues .....	230
6.1.2	Cutaway Illustration .....	236
6.1.3	Comprehensive Rendering via Composite Viewpoints .....	239
6.2	Shape-conveying Illustrations .....	241
6.2.1	Expressing Shape Features via Stroke Texture .....	241
6.2.2	Expressing Shape Features by Selective Depiction .....	243
6.3	Intent-based 3D Illustration .....	249
6.3.1	Intent Communication by Multimedia Presentation .....	250
6.3.2	Interpreting Intent by Graphical Abstraction .....	252
6.3.3	Visual Explanation of Iconic Symbols .....	254
6.4	Expressive Rendering for Transparency .....	255
6.5	Summary .....	259
	References .....	260
<b>7</b>	<b>Computer-assisted Cartoon Animation by Traditional Production Pipeline .....</b>	<b>263</b>
7.1	The Traditional Animation Process .....	263
7.2	The Role of the Computer in Traditional 2D Animation .....	268
7.3	Computer-assisted Coloring .....	270
7.3.1	Auto-coloring of Inbetweening Frames .....	271
7.3.2	Colorizing Black-and-white Cartoons .....	277
7.4	Computer-assisted Inbetweening .....	282

7.4.1	Generation of Inbetween Poses .....	282
7.4.2	Generation of inbetweening Facial Expression .....	288
7.5	Summary .....	290
	References .....	291
<b>8</b>	<b>Novel Approaches to Computer-assisted Cartoon Animation .....</b>	<b>293</b>
8.1	Video Driven Cartoon Animation .....	294
8.1.1	Directly Converting Video Segment into Painterly Animation .....	294
8.1.2	Contour-based Animation Generation from Video ....	300
8.1.3	Video-driven Facial Animation with Style .....	303
8.2	Cartoon Production Integrated with 3D Geometric Elements .	310
8.2.1	Automated inbetweening by the 3D Approximate Model .....	311
8.2.2	Cartoon Animation by 3D Canvas .....	315
8.2.3	Cartoon Animation by View-dependent Geometry ....	318
8.3	Cartoon Generation by Temporal Coherent Rendering .....	322
8.4	Cartoon Generation Together with 3D Graphical Processing Techniques .....	327
8.4.1	Cartoon Production Integrated with 3D Transformation .....	327
8.4.2	Cartoon Animation Enhanced with Artistic Texture Mapping .....	330
8.4.3	Cartoon Motions Augmented by 3D Physical Models..	331
8.4.4	Stylized Highlight and Shadow Generation for Cartoon Animation .....	334
8.5	Cartoon Production via Reuse of Traditional Animation ....	336
8.5.1	Reusing Visual Style for Cartoon Animation .....	337
8.5.2	Reusing Motions for Cartoon Animation .....	340
8.6	Summary .....	343
	References .....	345
<b>9</b>	<b>Perspectives of Non-photorealistic Computer Graphics ...</b>	<b>349</b>
	References .....	353
	<b>Index .....</b>	<b>355</b>

## Introduction

Non-photorealistic computer graphics are used to imitate the eyes and minds of artists and designers to create, view, and depict the graphical world. These computer-generated graphics are used instead of achieving the illusion of photorealism via an optical camera. With the advent of many algorithms, papers, and software tools dedicated to generating the artistic and meaningful images, the entire field was exploded into existence in the 1990s. Now the field appears to be approaching maturity. Many questions remain open, but many have been settled. This book presents a detailed treatment of this field in a coherent conceptual framework.

### 1.1 The Brief History: from Photorealism to Non-photorealism

Photorealism in the context of computer graphics is a “faithful” rendering of the material world based on a number of depiction principles, such as convincing details, anatomical correctness, correct color rendition, and the correct perceptions of space, volume, and texture, etc. Therefore this field of computer graphics is also called *photorealistic rendering*, denoting algorithmic techniques that resemble the output of a photographic camera even make use of the physical laws being involved in the process of photography. A truly photorealistic image needs to be generated accurately from an extremely detailed object description requiring a great modeling effort. For the time being, a vast number of different computational models have been explored that to approximate these physical processes. The creation of realistic pictures has made great progress in the computer graphics community. This can be judged by viewing feature films and TV commercials, where it is often impossible for the audience to decide which are the virtual objects generated by the computer and which are the real objects captured by the camera.

It is no doubt that highly realistic graphics are very useful, e.g., they can support designers to evaluate and refine new products and turn computer

games into a more enjoyable experience. But in general photorealism considers only part of the imagery traditionally used in simulation, design, entertainment, advertising, research and education, etc. For instance, it may be useful for designers to be able to generate photorealistic images of the finished product. But, during the design process they prefer to work with sketches and conceptual drawings that are better suited for explaining the basic concept of a new product or showing its inner structure. In educational course books, most of the pictures are not photographs, but rather diagrams and illustrations that are better able to communicate the important aspects of a topic. Furthermore, there are many research areas that can benefit from automatically generated images based on purely abstract data. But, how can one create photorealistic images of data that have no counterpart in the visual world? As computer graphic is getting closer to its holy grail of achieving photorealism, people finally realizes that there is more to images than realism, and, computer-generated imagery should not be restricted to photorealistic renderings.

Thus a new type of quest has emerged—creating imagery that is more effective at conveying information, expressive or beautiful—rather than just being physically realistic. Researchers started to explore alternative rendering techniques other than mimicking the effect of a traditional photographic camera. They needed to differentiate themselves from the rest of the computer graphics community, and *non-photorealism* was thus proposed. From the point of view of rendering an image, non-photorealistic images can be anything from a drawing or a diagram to a painting, as long as it helps to communicate the intended idea.

## 1.2 What is Non-photorealistic Computer Graphics

As with many new and young areas of scientific endeavor, there is no uniform definition of what we have called non-photorealistic computer graphics. The border between photorealism and non-photorealism is also fuzzy. Examining the primary literature on the topic, a number of different points of view have been summarized as follows [Gooch & Gooch, 2001; Strothotte & Schlechtweg, 2002]:

- (1) The process of image production that is being mimicked (or non-photorealistic to be more precise, processes that are definitely not being mimicked): *non-photorealistic rendering*.
- (2) The freedom not to have to reproduce the appearance of objects precisely as they are: *non-realistic rendering*.
- (3) The process of adapting presentation to a dialog context and the dynamic informational wishes of users: *abstraction*.
- (4) A specific drawing style: the terms *sketch rendering*, *pen-and-ink illustration*, and *stipple rendering* are examples.

- (5) The effect a rendition has (or will hopefully have) on its viewers: *comprehensible rendering*.
- (6) The use of renditions for conveying information, perhaps in the context of other media of expression: *illustrative rendering*, or *expressive illustration*.
- (7) The possible deformations of images: *elastic presentations*.

In order to better explain non-photorealistic computer graphics, we will first explore the fundamental concepts of image, picture, and visualization for visual representation. We will then further discuss the essential aspects of non-photorealistic computer graphics by comparing the photorealistic and non-photorealistic computer graphics in terms of their goals and algorithmic techniques.

### 1.2.1 Image, Picture, and Visualization

Image, picture, and visualization are the different levels of visual representations. They are often mixed when used to describe the resulting output of a rendering in the computer graphics community. In order to help readers to better understand the rest of this book, these vocabularies should be clarified from the point of view of computer depiction. Computer depiction deals with all aspects of picture production, encompassing both photorealistic and non-photorealistic styles. Based on the definitions from the Webster dictionary, the differences between image, picture, and visualization are given as follows [Durand, 2002]:

- (1) *Image*. An image is a “reproduction or imitation”, or “the optical counterpart of an object” [Webster, 1983]. It is an optically formed duplicate, characterized by optical accuracy to a visual scene or object.
- (2) *Picture*. A picture is “a design or representation”, or “a description so vivid or graphic as to suggest a mental image or give an accurate idea of something” [Webster, 1983]. A picture is more loosely defined than an image, and it corresponds to both to the graphical object and to a representation. Pictures always have a purpose, which can be a message, collaborative work, education, aesthetics, emotions, etc. The term “picture” can be used to describe a visual representation of a visual scene, but this representation is not necessarily optically accurate. Moreover, a picture is not necessarily the representation of an existing real scene or object. The extreme example of impossible figures shows that a picture can superficially look like the representation of a 3D reality, while no objective scene that can be projected to such a picture.
- (3) *Visualization*. Visualization is “the act or process of interpreting in visual terms or of putting in visual form” [Webster, 1983]. A visualization can represent visually data or subjects that are not themselves visual. Visualization therefore mainly relies on metaphors to communicate the meaningful information to the audience.

### 1.2.2 Photorealistic versus Non-photorealistic Rendering

The major goal of photorealistic rendering is to generate images that mimic the effect of a traditional photographic camera. It depicts only “What I See”—the extrinsic properties of objects such as outgoing light varying with light conditions, and the resultant output is a photography-like image. Its rendering process is a unidirectional optical projection of a 3D model onto a 2D plane. A scene consisting of 3D objects is illuminated by a number of virtual light sources, and images are generated by a virtual camera that is placed in the scene. The idea is to generate 2D images of the scene by emitting light from the light sources into the scene, computing the interaction of the light with the surface of the 3D models, and capturing that portion of the light that reaches the camera on a virtual film plate.

Non-photorealistic rendering (NPR), not only depicts “What I See”, but also depicts “What I Know”—the intrinsic parameters and constancy that are invariant and constant properties of the objects such as reflectance and relative sizes. This gives freedom to encode an impression of the scenes rather than being forced to follow physical constraints. Its resulting output is a hybrid picture balanced between extrinsic and intrinsic properties of objects. The NPR process is a bi-directional interaction between a 3D model and a 2D plane, involving feedback and influence from the picture space to the object space. Therefore the NPR is essentially becoming a very complex optimization problem, producing the best picture with back-and-forth exchanges, given constraints, and goals linking the scene and the picture.

The function to minimize image information, and the degrees of freedom to vary it, heavily depend on the rendering of context and goal. For example, the goals and constraints for picture creation of art and craft are often set by the medium, the social context, the artistic fashion, clarity, representation of intrinsic vs. extrinsic qualities, 2D layout, etc. There are three main strategies to solve this optimization problem. The user can solve it, the computer can solve it, or the solution might involve both user and computer decisions. All approaches are of course not contradictory and can be blended. The frequently used case is the mixed one. The computer has to make decisions automatically, but the user needs to keep some control and influence the decisions. For example, in game and movie making, it is the equivalent of the movie director wanting to keep control of the style of the pictures, and the computer has to respond automatically to the user’s interaction.

As a summary, the differences between photorealistic and NPR are investigated as follows:

- (1) *Content of rendition.* Photorealistic rendering is merely based on the 3D geometry and topological information of the scene, and the resulting image is an “objective” depiction of that scene, and nothing else. In contrast, NPR encodes the “subjective” artifacts into the picture that clearly do not exist in the world. These artifacts may stem from the way

in which the geometric model represents the original object, or result from the manner, or style in which the geometric model is rendered.

- (2) *Manners for presentation.* In photorealistic rendering, the external world is presented in an “objective” way. The depiction corresponds exactly to the object being modeled, following physical constraints and leaving nothing for the imagination. However, the presentation manner in NPR is a graphical abstraction such that the resultant picture comes from, and is “higher” than the underlying models, with certain features of the model being enhanced. It gives freedom to encode an impression of scenes, and introduce a broader variety of styles. This not only enables better recognition of certain features of the object being modeled by changing the model, but also enables selected features of the geometric model to be exaggerated in the rendition, in order to emphasize them. Moreover, it can show more of the relevant parts of an object than what would otherwise be possible, while less relevant parts may no longer be visible.
- (3) *The cognition process of the resulting depiction.* The output of photorealistic rendering comes from the intuitive observation of the real world, and its cognition process is consistent with the visual perception of human beings in their daily lives. However, a reasoning process is needed to interpret non-photorealistic images. It is assumed that the viewers are able to build up a mental model of the object being portrayed with creative thinking and imagination, and then to perform the cognitive process for the visual understanding of the NPR results. This reasoning process gives the greatest communicative power for NPR.
- (4) *The algorithmic mechanism.* The photorealistic rendering technique is based on the working model of another kind of machine, a camera. It simulates the particle-by-particle lighting exposure principle with the pixel-by-pixel rendering mechanism. The correspondence between pixels and the drawn primitive object is direct. In contrast to the pixel-by-pixel mechanism, NPR employs a relative global mechanism beyond pixels, and paints. The resulting picture is in a region-by-region mode. Each region has a set of pixels with attributes of shape, an area as a whole. These regions may be formed by a stroke, or more generally, may come from the interactional areas between the pen/brush with the canvas.
- (5) *The interplay between 3D and 2D aspects of depiction.* Photorealistic rendering is a unidirectional projection from a 3D objective scene onto a 2D image. The typical object space inputs are a 3D geometric description of the objects, their material properties, and light sources. Perspective matrices, hidden-surface removal, and lighting simulation are then used to project this model onto the 2D image. However, the NPR is a complex bi-directional process between the 2D picture and the 3D model. A typical feedback loop is that the user and the computer work together, cooperatively generating an initial picture, viewing it, assessing the qualities, and then re-generating the new interim pictures via necessary modifica-

tions and refinements. The process is iterated, and the final picture is retouched until it looks right.

### 1.3 The Framework for Non-photorealistic Computer Graphics

The default tendency of non-photorealistic computer graphics is to generate imagery that superficially looks like that made by artists [Lansdown & Schofield, 1995]. It involves a fundamental issue of simulating the intelligence of artists, i.e., to emulate human facilities for producing an artist's handwork. Artists and other picture makers have developed a rich set of techniques to produce effective pictures. Non-photorealistic computer graphics should learn from this large body of knowledge, as well as from the analysis performed in the perception community. However, fine arts are still believed to be of a purely "metaphysical" nature and that there is no underlying theoretical knowledge of them. Every creative act is partly guided by intangible "forces" and "feelings" that are not easily translatable to algorithms.

Non-photorealistic computer graphics not only has been concerned with simulating traditional drawing and painting techniques, but also aims at improving visualization based on the findings from cognitive psychology. Conveying meaning is beyond scientific curiosity for pursuing NPR. There is ample evidence that non-photorealistic renditions are in fact more effective for communicating specific information than photographs of photorealistic renditions in many situations. Many studies have been carried out by cognitive and educational psychologists that attest to the superiority of such handmade graphics over photo-like images. NPR therefore enables users to lead human-computer dialogs with information exchange in a graphical form. The style of the picture generated should be flexible so as to be most appropriate for the dialog at hand. To this end, a model of information transfer must be assumed or developed. Methods and tools need to be developed to enable designers and programmers of interactive systems to have appropriate pictures rendered for their end users.

The core scientific problems in non-photorealistic computer graphics can be categorized as the following ones in terms of its input/output information.

- (1) *How to create art crafts from a blank canvas.* When an artist sets out to paint a picture, he or she must have three types of physical tools. The first is a medium, such as oil paint, acrylic or watercolor, to be used to construct the picture. The second is some type of applicator or brush/pen for the application of the medium. The third is a surface, such as paper or canvas, on which the medium is applied. Therefore the computer should first model and simulate these authoring tools and the physical interaction among them, and then the user can employ the



digitized authoring tools to interactively or semi-automatically create the art craft of pen-and-ink illustration, watercolor/oil painting, or engraving.

- (2) *How to convert the source images into pictures with the desirable visual effects.* By the techniques from image processing, analogical reasoning, computer vision, etc., it attempts to semi-automatically translate the input images into the resulting pictures with the desired artistic styles, which may be specified by numerical parameters, textual keywords, or the reference images.
- (3) *How to generate artistic renditions from 3D models.* Its input is a 3D model of the scene, character, the viewpoint, etc., and the algorithmic steps for rendering are very similar to those in photorealistic renderings. However, the affine transformations, viewing projections, texture-mappings or lighting models are usually with non-photorealistic properties, and can help generate the output picture, which gives the visual impression of the artistic rendition styles specified by the user.
- (4) *How to synthesize expressive pictures from textual, graphical or pictorial data.* The “expressive” picture embodies various levels of meaning for the communication among artists and designers. Its input might be a combination of 3D models, 2D images, or semantic text. It attempts to render objects and scenes to resemble how artists and designers might want to see them. The resulting pictures are made meaningful and comprehensible. The viewer is encouraged to make the same imaginative, perceptual contributions as those in the interpretive art.
- (5) *How to accelerate the production of cartoon animation sequences with temporal coherence.* 2D animation can only be automated to the extent that the computer acts as an interactive assistant to the animator. The key problem is that the modeling, rendering and motion which are implicitly and tightly coupled in the animated drawings of key frames are unavailable. The temporal coherence problem will arise if we want to speed up the cartoon animation production by decoupling the modeling, rendering, and motion as that in 3D animation production. For example, some features of the frames in a cartoon sequence are chosen randomly (e.g., stroke placement for hatching), and they will look different in each frame. Although this may be desirable in some cases, it will in general distract the beholders’ attention, and can put a considerable strain on the eyes. Similar artifacts appear if the rendering algorithm is unstable with respect to small changes of the viewing angle or small body deformations. It is therefore important to ensure that small (or no) changes in the scene result only in small changes in the cartoon animation production.

This book is accordingly organized in terms of the aforementioned five scientific core issues, providing a systematic, in-depth insight into non-photorealistic computer graphics. The structure of the book is shown in Fig. 1.1.