Video Codec Design
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Introduction

1.1 IMAGE AND VIDEO COMPRESSION

The subject of this book is the compression ('coding') of digital images and video. Within the last 5–10 years, image and video coding have gone from being relatively esoteric research subjects with few 'real' applications to become key technologies for a wide range of mass-market applications, from personal computers to television.

Like many other recent technological developments, the emergence of video and image coding in the mass market is due to convergence of a number of areas. Cheap and powerful processors, fast network access, the ubiquitous Internet and a large-scale research and standardisation effort have all contributed to the development of image and video coding technologies. Coding has enabled a host of new 'multimedia' applications including digital television, digital versatile disk (DVD) movies, streaming Internet video, home digital photography and video conferencing.

Compression coding bridges a crucial gap in each of these applications: the gap between the user's demands (high-quality still and moving images, delivered quickly at a reasonable cost) and the limited capabilities of transmission networks and storage devices. For example, a 'television-quality' digital video signal requires 216 Mbits of storage or transmission capacity for one second of video. Transmission of this type of signal in real time is beyond the capabilities of most present-day communications networks. A 2-hour movie (uncompressed) requires over 194 Gbytes of storage, equivalent to 42 DVDs or 304 CD-ROMs. In order for digital video to become a plausible alternative to its analogue predecessors (analogue television or VHS videotape), it has been necessary to develop methods of reducing or compressing this prohibitively high bit-rate signal.

The drive to solve this problem has taken several decades and massive efforts in research, development and standardisation (and work continues to improve existing methods and develop new coding paradigms). However, efficient compression methods are now a firmly established component of the new digital media technologies such as digital television and DVD-video. A welcome side effect of these developments is that video and image compression has enabled many novel visual communication applications that would not have previously been possible. Some areas have taken off more quickly than others (for example, the long-predicted boom in video conferencing has yet to appear), but there is no doubt that visual compression is here to stay. Every new PC has a number of designed-in features specifically to support and accelerate video compression algorithms. Most developed nations have a timetable for stopping the transmission of analogue television, after which all television receivers will need compression technology to decode and display TV images. VHS videotapes are finally being replaced by DVDs which can be played back on

DVD players or on PCs. The heart of all of these applications is the video compressor and decompressor; or enCOder/DECoder; or *video CODEC*.

1.2 VIDEO CODEC DESIGN

Video CODEC technology has in the past been something of a 'black art' known only to a small community of academics and technical experts, partly because of the lack of approachable, practical literature on the subject. One view of image and video coding is as a mathematical process. The video coding field poses a number of interesting mathematical problems and this means that much of the literature on the subject is, of necessity, highly mathematical. Such a treatment is important for developing the fundamental concepts of compression but can be bewildering for an engineer or developer who wants to put compression into practice. The increasing prevalence of digital video applications has led to the publication of more approachable texts on the subject: unfortunately, some of these offer at best a superficial treatment of the issues, which can be equally unhelpful.

This book aims to fill a gap in the market between theoretical and over-simplified texts on video coding. It is written primarily from a design and implementation perspective. Much work has been done over the last two decades in developing a portfolio of practical techniques and approaches to video compression coding as well as a large body of theoretical research. A grasp of these design techniques, trade-offs and performance issues is important to anyone who needs to design, specify or interface to video CODECs. This book emphasises these practical considerations rather than rigorous mathematical theory and concentrates on the current generation of video coding systems, embodied by the MPEG-2, MPEG-4 and H.263 standards. By presenting the practicalities of video CODEC design in an approachable way it is hoped that this book will help to demystify this important technology.

1.3 STRUCTURE OF THIS BOOK

The book is organised in three main sections (Figure 1.1). We deal first with the fundamental concepts of digital video, image and video compression and the main international standards for video coding (Chapters 2–5). The second section (Chapters 6–9) covers the key components of video CODECs in some detail. Finally, Chapters 10–14 discuss system design issues and present some design case studies.

Chapter 2, 'Digital Video', explains the concepts of video capture, representation and display; discusses the way in which we perceive visual information; compares methods for measuring and evaluate visual 'quality'; and lists some applications of digital video.

Chapter 3, 'Image and Video Compression Fundamentals', examines the requirements for video and image compression and describes the components of a 'generic' image CODEC and video CODEC. (Note: this chapter deliberately avoids discussing technical or standard-specific details of image and video compression.)

Chapter 4, 'JPEG and MPEG', describes the operation of the international standards bodies and introduces the ISO image and video compression standards: JPEG, Motion JPEG and JPEG-2000 for images and MPEG-1, MPEG-2 and MPEG-4 for moving video.

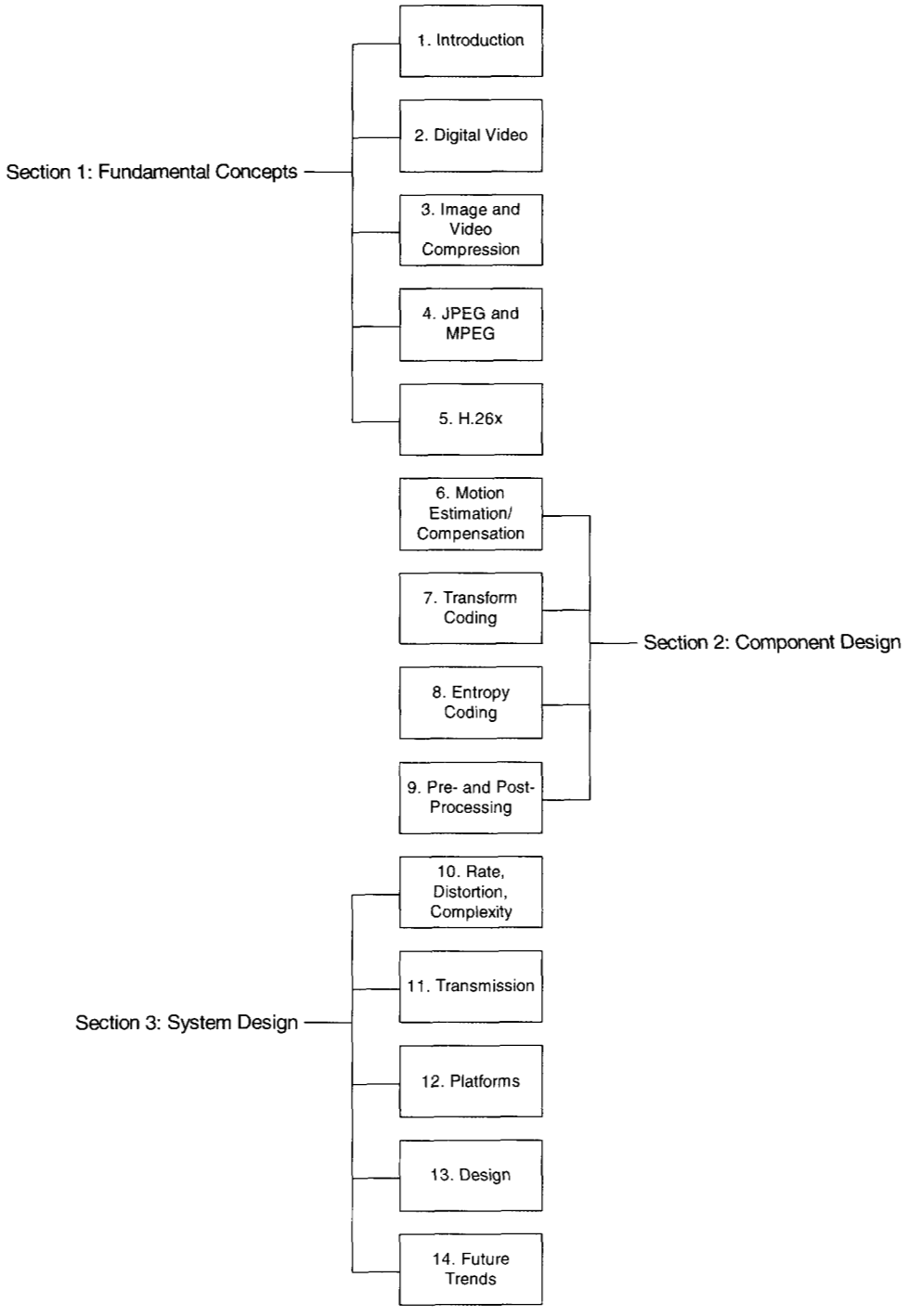

Figure 1.1 Structure of the book

Chapter 5, 'H.261, H.263 and H.26L', explains the concepts of the ITU-T video coding standards H.261 and H.263 and the emerging H.26L. The chapter ends with a comparison of the performance of the main image and video coding standards.

Chapter 6, 'Motion Estimation and Compensation', deals with the 'front end' of a video CODEC. The requirements and goals of motion-compensated prediction are explained and the chapter discusses a number of practical approaches to motion estimation in software or hardware designs.

Chapter 7, 'Transform Coding', concentrates mainly on the popular discrete cosine transform. The theory behind the DCT is introduced and practical algorithms for calculating the forward and inverse DCT are described. The discrete wavelet transform (an increasingly popular alternative to the DCT) and the process of quantisation (closely linked to transform coding) are discussed.

Chapter 8, 'Entropy Coding', explains the statistical compression process that forms the final step in a video encoder; shows how Huffman code tables are designed and used; introduces arithmetic coding; and describes practical entropy encoder and decoder designs.

Chapter 9, 'Pre- and Post-processing', addresses the important issue of input and output processing; shows how pre-filtering can improve compression performance; and examines a number of post-filtering techniques, from simple de-blocking filters to computationally complex, high-performance algorithms.

Chapter 10, 'Rate, Distortion and Complexity', discusses the relationships between compressed bit rate, visual distortion and computational complexity in a 'lossy' video CODEC; describes rate control algorithms for different transmission environments; and introduces the emerging techniques of variable-complexity coding that allow the designer to trade computational complexity against visual quality.

Chapter 11, 'Transmission of Coded Video', addresses the influence of the transmission environment on video CODEC design; discusses the quality of service required by a video CODEC and provided by typical transport scenarios; and examines ways in which quality of service can be 'matched' between the CODEC and the network to maximise visual quality.

Chapter 12, 'Platforms', describes a number of alternative platforms for implementing practical video CODECs, ranging from general-purpose PC processors to custom-designed hardware platforms.

Chapter 13, 'Video CODEC Design', brings together a number of the themes discussed in previous chapters and discusses how they influence the design of video CODECs; examines the interfaces between a video CODEC and other system components; and presents two design studies, a software CODEC and a hardware CODEC.

Chapter 14, 'Future Developments', summarises some of the recent work in research and development that will influence the next generation of video CODECs.

Each chapter includes references to papers and websites that are relevant to the topic. The bibliography lists a number of books that may be useful for further reading and a companion web site to the book may be found at:

http://www.vcodex.com/videocodecdesign/