A survey of computer vision education and text resources

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Abstract

This paper provides a survey of the variety of computer vision [CV] and image processing [IP] courses being taught at institutions around the world. This survey shows that, in addition to classic survey courses in CV/IP, there are many focused and multi-disciplinary courses being taught that reportedly improve both student and faculty interest in the topic. The survey also demonstrates that students can successfully undertake a variety of complex lab assignments. This paper also includes a comparative review of several textbooks and supplemental texts appropriate for CV/IP courses.

1 Introduction

Ten years ago, an undergraduate computer vision course was not a common feature of many engineering or computer science curricula. A digital image processing course was more common, but generally as an application of signal processing techniques within an EE/CompE program. Today, however, a larger number of institutions offer computer vision courses at the undergraduate level. In some cases the CV courses are offered as a complement or continuation of an IP course, in other cases as a standalone elective.

Along with this increase in image computation-related courses is an attendant increase in new CV/IP educators. When an educator begins to plan a course they must select a text and then plan topics, a syllabus, and lab/programming assignments. Unless they spend a significant amount of time talking with other educators or searching for course web pages, the inspiration for texts, lab assignments, and topics comes largely from their own CV/IP education and interests.

There is a lot of good, successful CV/IP education going on, however, that we can and should draw upon to develop high quality courses. To that end, this paper presents a snapshot of CV/IP education around the world. This includes both a survey of the variety of courses being offered and a review of texts and supplemental materials.

As discovered through the survey--discussed in section 2--many undergraduate CV/IP courses are general survey courses that cover something approaching a standard list of topics. However, education has also begun to follow CV/IP research into interdisciplinary areas such as biological perception, perceptual grouping, and human-computer interfaces. Educators are also experimenting with adding a focus to their courses, modifying the order and list of topics they cover to highlight a particular area or application of CV/IP. These new directions are apparently improving both student and faculty interest.

The remainder of the paper is organized as follows. Section 2 attempts to provide a summary of the trends and new directions in CV education. Hopefully, the specific and summary information will provide inspiration to educators as they try to plan their courses. Section 3 then reviews some of the currently available textbooks and supplemental texts that are appropriate for a CV/IP course. This comparative review is meant to be complementary to the author's previous comparative reviews in [8] and [9].

2 Survey of computer vision education

The author used two methods to collect information about computer vision courses currently being taught at both the undergraduate and graduate level. The first was to send an email survey to several mailing lists--ACM SIGCSE, 1997 IEEE Workshop on Undergraduate Education and Image Computation--and selected individuals; the second was to locate computer vision course web pages and review syllabi, lab assignments, and reading assignments.

As of this writing, the author has received 14 surveys and reviewed 23 course web pages--including 11 of the 14 who returned a survey--for a total of 27 different courses at 25 different institutions. This section summarize the findings and hopefully provides a starting point for educators developing new courses or revising existing ones.

The survey--which readers are requested to fill out at http://www.palantir.swarthmore.edu/~maxwell/visionCourses.htm--contains twelve questions. They are included here for reference.

1. Please list the title of the course and give a 1 sentence description.
2. Please list all textbooks for the course. Also, please indicate whether you used a significant number of papers/handouts in addition to/instead of a textbook.
3. For each textbook, please rate it on a scale of 1-4 (1: hated it, 2: OK but would like something else, 3: pretty good, 4: would recommend it and use it again).
4. Would you consider the course a survey course in either image processing or computer vision?
5. Did you have a focus in your course?
6. Did you feel that having a focus improved the interest level of the students?
7. Did you feel that having a focus improved your interest in teaching the course?
8. How many labs/assignments did you have for the course?
9. Please give a 1 sentence description of the most successful lab/assignment.
10. Please give a 1 sentence description of the least successful lab/assignment.
11. Has any of the students' work during the course resulted in a publication?
12. If you have a web page for the course, please give the URL below.

For the purposes of discussion, the survey and web search results are integrated for questions 1, 2, 4, 5, 8, and 12 where the answers exist on or can be synthesized from the course web pages. Links to all of the course web pages used in this survey exist at the URL above.

Questions 1,4. The courses show a wide variety of focuses and topics. They group roughly into five categories: classic IP, classic CV, application oriented, focused CV courses, and high-level vision. The classic IP and CV courses--which constitute 12 of the 27 courses-- present a survey of topics designed to provide breadth of knowledge in computer vision/image processing. Variation in these courses appears primarily in the lab work and assignments that vary in complexity and scope.

The application oriented courses--either self-described or inferred from the web pages--focus on functioning vision systems and labs that apply vision to existing problems. The implied trade-off is that more theoretical topics in CV are covered in less depth if at all. Three of the courses identified themselves in this category. The specific applications varied from mechanical and production engineering tasks to optical character recognition to detection of calcification in mammograms.

The focused CV courses, of which there were four, present the CV material as it applies to a specific focus task. In two cases the focus was object recognition [OR], in the third motion analysis and content-based image retrieval, and in the fourth robot perception. The author's CV course falls in this category. In the author's course the material covered in lectures does not, in general, differ greatly in scope from a classic CV course. However, the order of presentation is somewhat different, and there is an attempt to focus on applying the CV techniques to the selected focus. In the author's course, for example, color vision is covered more in-depth and each of the three main labs had students implement a different object recognition system. The two OR focused courses in this section included more AI/machine learning topics than the classic CV courses, the robot perception course focused on extracting 3D information and models, and the motion/CBIR course included significantly more optical flow analysis and grouping and segmentation when compared to classic CV courses.

Finally, the high-level vision courses focused on advanced topics in CV. There were seven in this category. Three of them focused on current research topics--monitoring, 3D imaging, HCI systems--three focused on perceptual grouping for segmentation and OR, and the seventh course focused on a combination of biological and computer perception. The latter courses, in particular, are examples of hybrid courses that are merging computer vision with cognitive science, biology, and psychology. This seems to be a new direction in CV education (reflecting an existing trend in research), and one that is hopefully the harbinger of more interdisciplinary CV curricula.

Questions 2-3. The 27 courses used seven different textbooks, not including paper based courses, with *Image Processing Analysis and Machine Vision* by Sonka *et. al*. [10] being the most common (7 of 27). Everyone using the book gave it the highest rating (4), indicating that they would recommend it to other educators. *Computer Vision* by Stockman & Shapiro [11] was the only other text to receive the highest rating, but since it is still pre-press, it has only been used in two courses so far.

The other books to receive ratings were--listed in order of their average rating--*Digital Image Processing* by Gonzalez & Woods [3], *Digital Image Processing* by Castleman [2], *Machine Vision* by Jain *et. al* [7], and *Introductory Techniques for 3-D Computer Vision* by Trucco & Verri [12]. Note that the image processing books were usually listed as supplementary materials. The other book in use by at least one educator--but not rated by any survey respondents--is Horn's *Robot Vision* [6].

Questions 5-7. While not a particularly scientific set of questions, two things were common among the answers. First, having a focus improved interest in the course for both students and faculty. Second, it increased the amount of work required for the faculty member in order to develop lectures, labs, and student reference materials. Hopefully, in the future this paper and other CV/IP educational resources can improve the availability of educational materials and help faculty to focus their courses without as large an overhead.

Questions 8-10. The number of labs in a CV/IP course ranged from 1 to 11, with the average being 3-4. The most successful labs reported by survey respondents were: Hough transform detection of circles in noisy images, detection of calcification in mammograms, face recognition using eigenfaces, visual combination lock (gesture recognition), quantifying blood flow from images, character enhancement for OCR, image segmentation (two courses), and image mosaics. From an educator's point of view, it is nice to see such a wide variety of successful projects. All of these labs appear to have two things in common. First, they deal with real-world images and problems, and second, they have immediate and intuitive results. Note that success in the task is not necessarily a requirement--but obviously helps retain student interest. At least one respondent indicated that the method used in the lab did not work extremely well, but the students enjoyed the lab anyway and learned a significant amount.

Labs that reportedly did not work as well included: object recognition by alignment, tracking soil grains in consecutive images, segmentation with histogram thresholding, and face recognition using eigenface and Gaussian pyramids to allow multi-scale recognition. Two out of four of these--the face recognition and OR by alignment--reportedly did not work as well because of the complexity of the task, debugging time, and the number of components required to get the system to work. Poor results are also not helpful in motivating student interest, as noted by other respondents to this question.

In the author's experience with OR by alignment, it is important to pick a data set that is commensurate with the amount of time the students have to deal with the task. In other words, the educator must minimize the number of modules required for successful implementation of the main method. In the case of OR by alignment, this means that foreground/background separation and feature finding should be extremely simple to implement so that students can focus on the alignment and classification issues. Even with a mildly complex data set--multi-colored 3D objects on a black background--the segmentation and feature location issues dominated the problem and reduced the amount of time students spent on the OR issues such as model development and matching techniques.

By contrast, the data set the author generated for a lab on face recognition using eigenfaces was extremely well-behaved (all the faces were approximately the same size and centered in the image), did not require any preprocessing, and allowed students to focus on the details of eigenspace recognition. It was by far the students' favorite lab.

Question 11. As perhaps would be expected, few of the undergraduate courses produced published work, while most of the graduate courses did. However, the important point here is that some of the undergraduate courses did produce publishable quality work. Clearly this will depend upon factors such as undergraduate student quality and preparation, but it is not the case that CV education and research are independent of one another.

Question 12. Almost all (23 of 27) of the courses included in this survey have web pages providing the syllabus, lab assignments, readings, and possibly lectures notes for the course. The following web page links all of these courses together in the hopes that it will be a useful educational resource.

URL: http://www.palantir.swarthmore.edu/~maxwell/visionCourses.htm

The author, for example, has a complete set of 35 lectures in a single Adobe PDF document that are freely available for use by other CV/IP educators.

2.1 Summary of survey results

Hopefully this review of computer vision education will provide both inspiration and resources for computer vision/image processing educators. There are a wide variety of courses being offered and, while the most common is still a CV/IP survey course, inter-disciplinary hybrids, application oriented courses, and focused CV courses exist that can be templates for curriculum development. In particular, the author urges educators to look at lab and homework assignments at other institutions to see the richness and complexity of the assigned tasks. What the survey and the author's research clearly demonstrate is that our students are capable of undertaking interesting and complex projects so long as appropriate tools and data sets are available for them to use.

3 Educational resources

One of the most important educational resources for both educators and students is a good textbook. It provides a framework for tying the material together, a reference and guide for complex material, and a source of both paper and hands-on exercises and study problems. Two of the ways you can tell the maturity of a field are A) how many textbooks are there, and B) how many of them are past their first edition. CV/IP has apparently reached middle age since there are now at least four current comprehensive CV texts--comprehensive IP texts have been around a bit longer--and at least one of them is a significantly revised second edition (Sonka *et. al.*).

In addition, there are a number of supplemental texts that may be appropriate for undergraduate or graduate vision and image computation courses. These supplemental texts are focused on a particular aspect of CV/IP and provide more depth in a particular area than is available in any other single source. Educators and students may find it useful either to have one of these books available as a strongly suggested text or to have one or more of them on reserve reading.

Finally, there are a class of applications-oriented texts that may be appropriate for CV/IP courses aimed at students who are not necessarily engineers or computer scientists. These texts are aimed at practitioners--potentially in the art and computer graphics realm--who need to use CV/IP tools, but do not need as in-depth an understanding of the algorithms and mathematics involved.

Based on these divisions, this section consists of four parts. Part one looks at the two most recent comprehensive computer vision texts: Sonka *et. al.*, and Stockman & Shapiro (based on their internet distribution). Part two briefly covers two standard IP texts: Gonzalez & Woods and Castleman. Part three looks at two of the application-oriented books: Baxes and Umbaugh. Finally, part four reviews two potential supplemental texts: Ullman and Fairchild.

For a comparative review of the more classic computer vision texts--*Robot Vision* by B. K. P. Horn, *Computer and Robot Vision* by R. Haralick, and L. Shapiro, *Machine Vision* by R. Jain, R. Kasturi, and B. Schunck, *Machine Vision* by E. R. Davies, and *A Guided Tour of Computer Vision* by V. S. Nalwa--please refer to [8].

3.1 Comprehensive Computer Vision Textbooks

***Image Processing, Analysis, and Machine Vision*, 2nd ed., M. Sonka, V. Hlavac, and R. Boyle, 1998.** This textbook is a comprehensive computer vision and image processing text. Its depth in some topics approaches that of the well-known *Computer and Robot Vision* by Haralick & Shapiro [5], but with an algorithmic and conceptual focus rather than a rigorous mathematical one. Like many other texts, *Image Processing, Analysis, & Machine Vision* begins with filtering, edge-finding, segmentation, and 2-D shape representation. The text then looks at various approaches to object recognition, including artificial neural networks, graph matching, and fuzzy logic. One of the strengths of this book is that it provides enough background on these topics for students to follow along. However, having an artificial intelligence, neural networks, or fuzzy logic course as prerequisite would improve students' ability to focus on the computer vision applications rather than the tools.

After object recognition, *Image Processing, Analysis, & Machine Vision* moves on to 3D vision including chapters on image understanding, 3D vision (calibration, stereo, and physics-based vision), and motion analysis. The book does not follow the same order as other texts, however, and later chapters include mathematical morphology, linear discrete transforms, and image compression, chapters that are often placed earlier in an image processing text. These chapters are almost as comprehensive on these subjects as the texts in the IP section, which makes this book appropriate for a CV, IP or hybrid course. This arrangement of topics is convenient for an undergraduate instructor, because these later chapters contain much of the material that is challenging for non-mathematically inclined students. Their placement later in the book, and the resulting implication that previous chapters do not depend on them for understanding, means an instructor can more easily pick and choose which of these topics to cover. Thus, they would be covered in a course focused on IP topics and possibly left out in a more CV-focused course.

The real strength of *Image Processing, Analysis, & Machine Vision* is its comprehensive, in-depth coverage of both CV and IP. The material is well-written and, while the mathematical formulation of methods is still the focus of the narrative, the text includes algorithms for many of the methods it covers. The text also seems to contain more example images and image comparisons than other texts, making it easier to obtain an intuitive understanding of the material. Its approach relies on a mixture of EE and CS concepts, and there is even a chapter on data structures for image analysis. Thus, with intelligent topic selection and adequate instruction this text is appropriate for students with a variety of backgrounds.

The book is written at a higher level than the other texts in this review, however, and instructors should carefully consider their prerequisites for a computer vision or image processing course before selecting this text. Based on its level and breadth, *Image Processing, Analysis, & Machine Vision* will be more accessible to students who have already had an artificial intelligence course, or related EE course that introduces them to artificial neural networks, search, and fuzzy logic. Students without this background could be overwhelmed with a range of new concepts that, while they are useful in computer vision, are not specific to the field.

One departure from other textbooks worth noting is that some methods that receive central coverage in other texts are de-emphasized, not mentioned, or placed in different contexts in *Image Processing, Analysis, & Machine Vision*. For example, the Hough transform is covered in the chapter on segmentation rather than within the chapter covering edge and line-finding. While line-finding is presented as an application of the Hough transform, this presentation comes after the line-finding chapter and in the middle of a discussion of segmentation. These issues are not a major drawback to the text, but an instructor should be aware of them and should structure the lectures and reading assignments appropriately.

Overall, *Image Processing, Analysis, & Machine Vision* is comprehensive CV/IP text and a good compromise with respect to level and target audience. Through strategic selection of chapters, it would be appropriate for either a senior level CS or EE undergraduate computer vision course, or an advanced graduate level course.

***Computer Vision*, G. Stockman & L. Shapiro, to appear in 2000.** The book presents a nice complement to *Image Processing, Analysis and Machine Vision* [IPAMV]. As the difference in names implies, *Computer Vision* is not appropriate as an image processing textbook. It contains sufficient information on image processing to implement computer vision algorithms, but the focus of the book is on image analysis and high-level vision. The result is that the combination of IPAMV and *Computer Vision* cover the spectrum from intensive image processing and manipulation to high level analysis, object recognition and content-based image retrieval.

Computer Vision contains sixteen chapters that fall into roughly four categories: overview, 2-D CV topics, 3D CV topics, and special CV topics. Since it was written with the intent of reaching a broader audience than IPAMV, this book is appropriate as a primary text or reference for a wider variety of courses. For example, it would be appropriate for courses ranging from an introduction to imaging for non-scientists to a sophomore-junior elective to a first-year graduate seminar.

The overview chapters (chapters 1-4) include a summary of problems in CV, imaging and image representations, simple binary image analysis and a survey of pattern recognition concepts. The 2-D processing topics (chapters 3, 5-7, and 11) include thresholding and binary image analysis, filtering and enhancement, edge detection, Fourier Transforms, color, texture, segmentation, and 2-D matching and pose calculation. The 3-D computer vision topics (chapters 9-10, and 12-14) include motion detection and analysis, range image analysis, stereo, calibration, intrinsic image analysis and line labeling, shape from X, and camera models. The special topics (chapters 6-8, 15-16) include color and shading, texture, content-based retrieval, virtual reality, and a set of case studies of CV systems. Different combinations of these are appropriate for different types of courses.

In comparison with other texts, the coverage of color and shading in *Computer Vision* is the best available without consulting a color reference such as Fairchild's *Color Appearance Models* (described below). However, it still does not contain adequate coverage of physical models of reflection or color appearance. The texture chapter is comparable to Sonka *et. al.*, and the CBIR and VR chapters are unique. It is these latter two areas that give *Computer Vision* a nice high-level flavor and provides a reference for these growing areas of CV.

Like IPAMV, *Computer Vision* contains a large number of example images, diagrams, and algorithms. The writing is clear and the mathematics--when it is necessary to present it--is complete and accessible. Since the book is designed with multiple audiences in mind, the heavy mathematical sections are flagged and the book can be used effectively with or without them.

Of particular interest to CV practitioners and students dealing with issues of calibration, chapter 13 contains a nice description of Roger Tsai's camera calibration algorithm, complete with an example.

Overall, the choice between *Computer Vision* and IPAMV should be based on personal preference, the focus of your course, and the background of your students. IPAMV will be more accessible to engineers and contains more in-depth coverage of image processing techniques. *Computer Vision* is more accessible to computer scientists and covers a number of higher-level aspects of CV that are either not covered or briefly covered in IPAMV. In a number of areas--texture, stereo, motion, calibration, and segmentation--the two books are quite similar and the differences are mainly in style and emphasis.

3.2 Image Processing

***Digital Image Processing*, R. Gonzalez and R. Woods, 1992.** Gonzalez & Woods' book is a standard textbook for an image processing (IP) course for engineers. It has also been used by educators as a supplemental text for CV courses (see section 2). Like all of the texts in this section, it covers digital image fundamentals, image transforms, image enhancement, image restoration, image compression, and image segmentation. Gonzalez & Woods (G&W) also provide a chapter on shape & region descriptors and a chapter on low-level recognition. The coverage of image transforms focuses on the Fourier transform, but also includes short sections on the Walsh, Hadamard, discrete cosine, Haar, slant, and Hotelling transforms. Because of the age of the book, however, wavelet transforms are not mentioned.

With respect to color image processing, G&W provide a 25 page section on the topic, including color plates that aid the presentation of the material. Castleman's book also provides a chapter on color and multi-spectral images.

***Digital Image Processing*, 2nd Ed. K. Castleman, 1996.** Castleman's book attempts to reach a broader audience than G&W, but is still most appropriate for an image processing course aimed at engineers or computer scientists with a strong linear systems background. Unlike G&W, who divide their book based on the major IP topics, Castleman divides the book into three parts based on complexity and overall theme. Part I presents basic IP concepts that do not rely heavily on mathematics. Part II covers IP techniques based on mathematical tools such as the Fourier and wavelet transforms, and the part III touches on computer vision topics and applications of IP.

The strength of Castleman's book is its extended coverage of both linear and discrete transforms, as well as the addition of wavelets. Part III also sets Castleman apart from G&W and the two other IP texts in this section. It contains chapters on segmentation, edge detection, line-finding, binary processing, texture and shape analysis, pattern matching, color image processing, and 3D imaging, including a short section on stereo. Because of this extended coverage, it could be an appropriate text for a two-semester EE course on image processing and computer vision. However, it is important to note that, when compared to other computer vision or comprehensive CVIP texts, it does not have the same breadth of CV topics or depth within each topic.

3.3 Applications oriented textbooks & supplements

***Digital Image Processing: Principles and Applications*, G. Baxes, 1994.** Unlike G&W and Castleman's texts, Baxes' text, like the following one by Umbaugh, is not aimed at engineers and students with a strong mathematical background. Instead, Baxes' and Umbaugh's texts address the needs of application programmers and people who need to understand and apply digital image processing techniques. From an educators point of view, these texts would be appropriate for a general education course on digital image processing and visual information systems. They would also be appropriate for an IP course for computer scientists who may, or may not have an adequate background to delve into linear and discrete transforms. Given the existence of digital cameras, cheap scanners, and the explosion of digital images available on the world-wide web, such a course is going to play an important role in the future of CVIP education.

Baxes divides his book into four parts. Part I presents an introduction to the field. Part II covers image enhancement and restoration, segmentation, feature extraction, simple object classification, image compression, and image synthesis. Part III looks at image processing systems, video formats, and image data handling, and part IV is a long list of image processing examples, demonstrating most of the concepts covered in the book. As a supplement to the text, the book contains a disk with implementations of a number of the algorithms.

The strength of this text, compared to Umbaugh, is the broader coverage of system topics. Both texts cover image compression, restoration, analysis, and segmentation. Baxes, however, also includes the visual information system topics and a chapter on image synthesis. The latter is particularly relevant to applications programmers and computer science students, and is unique to this book compared to any of the others in this review.

Where an educator may have to supplement the text are topics such as segmentation, edge and line finding, and filtering, which are not covered in detail.

***Computer Vision and Image Processing: A Practical Approach Using CVIPtools*, S. Umbaugh, 1997.** Umbaugh's book is the most limited in scope of the IP textbooks. The title is, unfortunately, somewhat misleading as this text is definitely focused on IP. The organization of the first section of this book is similar to G&W, with chapters on IP fundamentals, image analysis, restoration, enhancement, and compression. The second section is a reference for the CVIP code library and CVIP applications provided on a CD with the book.

The target audience for this text falls somewhere between Baxes and G&W, as it presents most concepts conceptually and algorithmically, while still providing more mathematical detail than Baxes. Like Baxes, this text would be appropriate for a computer science IP course, where not all students would be comfortable with a mathematical presentation of linear transforms.

The strength of Umbaugh's text is the CVIP library and applications provided with the book. In the author's experience it is the most extensive library of routines currently available with a textbook. It also has the most extensive documentation, which both students and educators should appreciate.

3.4 Supplemental texts

***High-level Vision: Object Recognition and Visual Cognition*, S. Ullman, 1996.** If the focus of your CV course is on object recognition--not an uncommon occurrence given the survey results--High-level Vision may be an appropriate supplemental text. The focus of this book is on object recognition by alignment but it covers a wider range of topics that nicely complement the CV texts.

The first two chapters of the book are a well-written introduction to object recognition. Chapter 2, in particular, summarizes the major approaches to recognition and provides a gentle introduction to the remainder of the book.

The primary OR by alignment section (chapters 3-5) covers alignment of rigid 3-D objects using affine transformation estimation, smooth boundary alignment, and view combination. These are the technical chapters of the book, but are written in an accessible manner for upper-class undergraduates. Detailed proofs and algorithms are reserved for the appendices, which contain sufficient detail to implement alignment by affine transformation estimation.

The remainder of the book looks at more general issues in OR and relates them to biological cognitive processing. These topics include segmentation, saliency and region selection, classification, correspondence, and visual cognition. These chapters contain less technical detail and are more an exploration of the major issues in each area. For a seminar or course with a small number of students, they provide a good basis for discussion of fundamental issues in OR.

Overall, if you want to focus your course on object recognition, *High-level Vision* will provide more in-depth coverage of OR by alignment and a stronger connection to biological processing than any currently available text. As a supplemental text or reserve reading it nicely complements other sources in a well-written and approachable manner.

***Color Appearance Models*, M. Fairchild, 1998.** One of the resources most lacking in current CV resources is comprehensive coverage of color vision. Fairchild's book provides a comprehensive discussion of what color means in terms of human perception, and how we can develop computational models that predict color perception. These models are relevant to color computer vision because they provide clues as to what characteristics of color are important from a biological standpoint--which is our working model.

The book divides into four sections: definitions and terminology, color phenomena, color appearance models, and applications or colorimetry. The introductory section (chapters 1-5) give an overview of the human visual system, psycho-physics, colorimetry, color appearance terminology, and color-order systems. These topics are directly relevant to any CV/IP course with a focus on color vision and will help students to think more clearly and precisely about color.

The second section (chapters 6-8) looks at well-known color phenomena in psycho-physical experiments. While perhaps not directly relevant to a machine vision system, it gives the reader a better understanding of some of the issues in color perception.

The third section (chapters 9-15) looks at a variety of computational color appearance models that predict human responses to various stimuli. Chapter 10 is particularly relevant to color computer vision and content-based image retrieval as it presents the CIELAB and CIELUV color spaces that attempt to match color distances with perceptual distances. All of the color appearance models are presented in sufficient mathematical detail that it is possible to implement them.

The final section of the book (chapters 16-18) is a summary of colorimetric applications and a discussion of device-independent color imaging. The latter topic is essential for any color machine vision person to know, since color depends so heavily on device characteristics.

Overall, like *High-level Vision, Color Appearance Models* is a useful supplemental text or reserve reading. It is well-written and approachable, especially the introductory and phenomena sections of the book, and there is no better resource for color science currently available.

4 Summary

Overall, the text resources available for computer vision educators are improving. In addition to two high quality main textbooks, there are now a number of useful supplemental texts that should enable educators to fine-tune their reading list.

In addition, the web resources available to educators are growing. Lab assignments, syllabi, reading lists, and lectures notes posted on the web create a wealth of inspiration and ideas when trying to decide what labs or readings to use during the upcoming semester. Even if you don't actually use anything you find, looking over the variety that exists will help you to come up with tasks that are both fun and challenging for your students.

Finally, in an effort to continue to improve the distribution of knowledge about CV education, the author encourages all CV/IP educators to submit a brief survey on their course(s) at the following web address.

http://www.palantir.swarthmore.edu/~maxwell/visionCourses.htm

5 References

[1] G. Baxes, *Digital Image Processing*, John Wiley & Sons, New York, NY, 1994.

[2] K. Castleman, *Digital Image Processing*, Prentice-Hall, Upper Saddle River, NJ, 1996.

[3] R. Gonzalez and R. Woods, *Digital Image Processing*, Addison-Wesley, Reading, MA, 1992.

[4] M. Fairchild, *Color Appearance Models*, Addison Wesley Longman Inc., Reading MA, 1998.

[5] R. Haralick and L. Shapiro, *Computer and Robot Vision*, Addison-Wesley, Reading, MA, 1992.

[6] B. K. P. Horn, *Robot Vision*, MIT Press, Cambridge, MA, 1985.

[7] R. Jain, R. Kasturi, and B. G. Schunck, *Machine Vision*, McGraw-Hill, New York, NY, 1995.

[8] B. A. Maxwell, “Teaching computer vision to computer scientists: issues and a comparative textbook review”, in *Int l Journal of Pattern Recognition and Artificial Intelligence*, Vol. 12, No. 8, pp. 1035-1051, August 1998.

[9] B. A. Maxwell “Comparative review of image processing and computer vision textbooks”, in *Proceedings of SPIE Medical Imaging ’98*, February, 1998.

[10] M. Sonka, V. Hlavac, and R. Boyle, Image Processing, Analysis, and Machine Vision, PWS Publishing, Pacific Grove, 1999.

[11] G. Stockman and L. Shapiro, *Computer Vision*, Prentice-Hall, Upper Saddle River, NJ, in press.

[12] E. Trucco, A. Verri, *Introductory Techniques for 3-D Computer*, Prentice-Hall, Upper Saddle River, NJ, 1998.

[13] S. Ullman, *High-level Vision: Object Recognition and Visual Cognition*, MIT Press, Cambridge, MA, 1996.

[14] S. Umbaugh, *Computer Vision and Image Processing: A Practical Approach Using CVIPtools*, Prentice-Hall, Upper Saddle River, NJ, 1998.