Advanced Information Technology

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Study Contents

- Digital Image Processing and its applications

Objective of the course

- Learn the basic principles of digital image processing

Questionnaire

- Studying on image processing or its applications
- Have learned about image processing (signal processing)
- Novice, but is interested in image processing
- Others

Lecture Plan #1

- 10/5 （M） Digital Image Processing #1
- 10/12 （M） Digital Image Processing #2+Exercises
- 10/19 （M） Digital Image Processing Demo+Answers
- 10/26 （M） Frequency of Image Signals #1
- 11/2 （M） Frequency of Image Signals #2+Exercises
- 11/9 （M） Fourier Trans. Demo＋Answers
- 11/16 （M） Multi-dimensional Filter #1

Lecture Plan #2

- 11/30 （M） Multi-dimensional Filter #2+Exercises
- 12/7 （M） Multi-dimensional Filter Demo + Answers
- 12/14 (M) Enhancement of Images + Exercises
- 12/21 （M） Enhancement of Images + Answers
- 01/4 （M） Geometric Transformation of Images
- 01/18 （M） Applications to Scientific Measurements
- 01/25 （M） Signal Processing in Geometric Modeling
- 02/1 （M） B-spline in Geometric Modeling

Lecture Styles

- PPT（Q&A anytime，examples）
- PPT print outs, hand out exercises
- Demo with MATLAB

Grading

- Attendance rate
- Performance of exercises

Others

- Questions
- Request

Image Signals

- Image information, in many cases, is transformed to [redacted] or [redacted] and is treated as image signals.

Generation of Image Signals

- Light is reflected on subjects.
- Reflected light is [redacted].
- Image signals are recorded on [redacted], or transformed to electrical signals by [redacted].

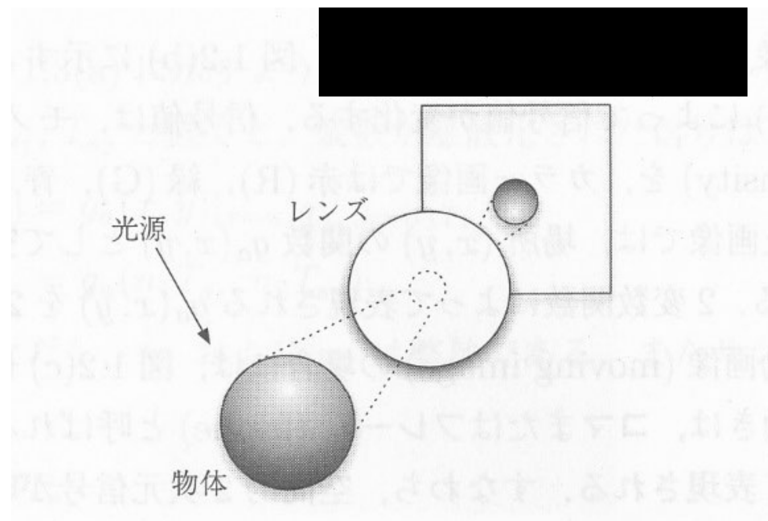
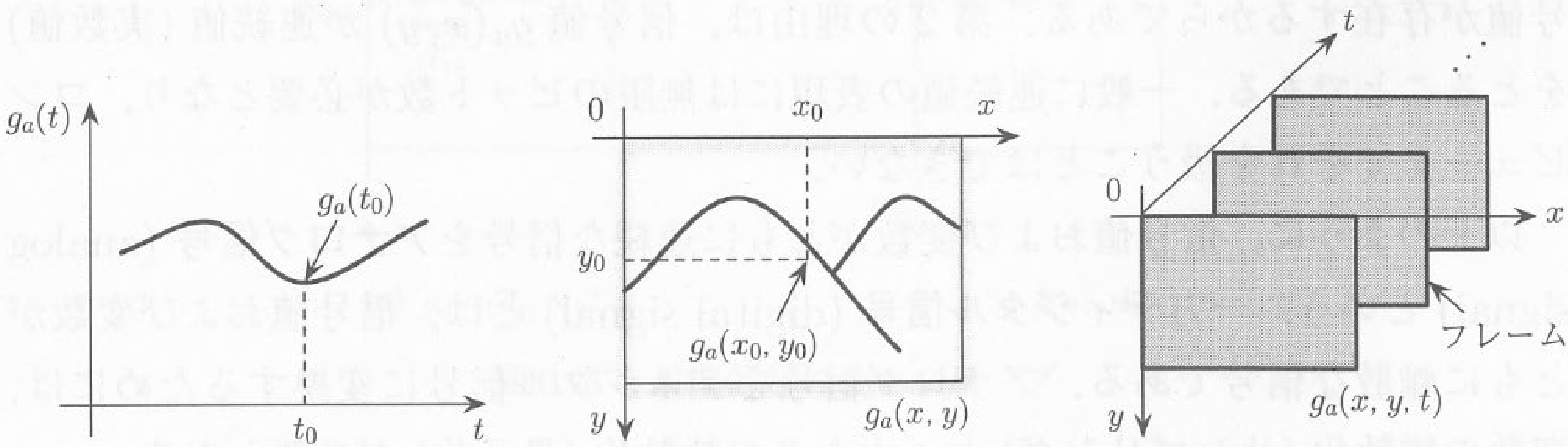


図 1.1　光学系による画像信号の生成

Dimension of Signals

- Signals, whose typical example is [redacted], is a function of time $g_a(t)$ of one dimensional signal.
- [redacted] is two dimensional signals and has various values at spacial position (x,y) .



(a) 1次元信号 (b) 2次元信号[redacted] (c) 3次元信号[redacted]

図 1.2 信号の次元

Digital Image

- Images taken by a digital camera are digital images and they are recorded as digital signals.
- Image processing processes digital signals by computers.

Analog Image Signals

- Intensities of [redacted] are analog signals and are given by two dimensional signal $g_a(x,y)$.
- Variables x and y are [redacted] and [redacted] which is a discrete space point is not defined.
- Signal values $g_a(x,y)$ are [redacted] and are not handled by computers because continuous values need infinite number of bits.

Digital Image Signals

- Image signals whose signals themselves g(x,y) and variables x, y are discrete.
- In order to convert analog signals to digital signals, it is necessary to discretize variables [redacted] and signals [redacted].

Sampling

- Process to discretize variables x and y.
- Let T_{s1}, T_{s2} be sampling intervals in x and y directions, respectively. The signal is given by

$$g(n_1, n_2) = g_a(x, y)|_{x=n_1 T_{s_1}, y=n_2 T_{s_2}}$$
$$= g_a(n_1 T_{s_1}, n_2 T_{s_2})$$

- n_1, n_2 are integers and reciprocals of sampling intervals Ts1, Ts2 are horizontal and vertical [redacted].
- A sample point in space is a [redacted] and its signal value is [redacted]

[redacted] Sampling

- It is commonly used because of simpleness of output devices and processing.
- The top-left corner is the image origin (0,0) and n_1 and n_2 are variables in the horizontal and vertical directions.

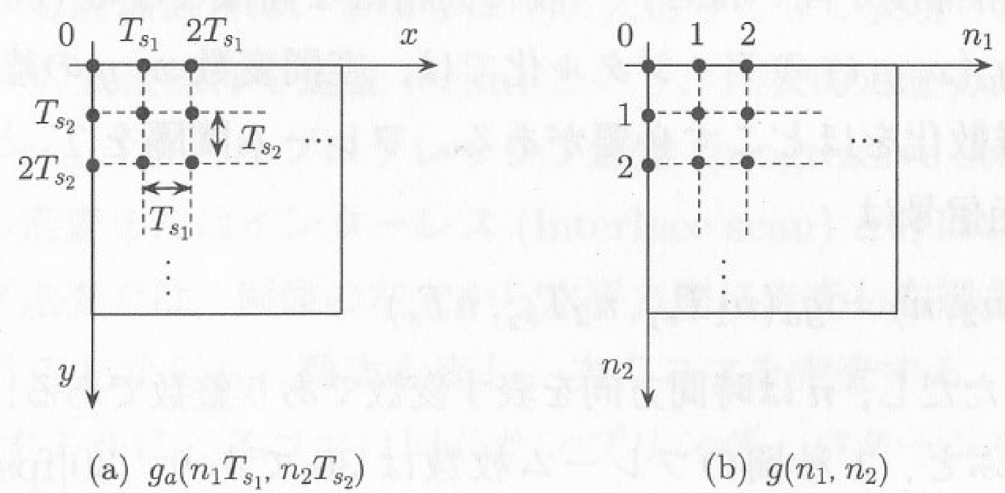


図 1.3 画像信号のサンプリング

[redacted] of Image

- For a digital image, let N_1, and N_2 be pixel numbers in the horizontal and vertical axes. Its space resolution is given by $N_1 \times N_2$.
- Higher space resolution, higher-definition
- VGA, HD, 4K ?

Digitization of Video Image Signal $g_a(x,y,t)$

- Discretize time variable tを by frame interval T_s.

$$g(n_1, n_2, n) = g_a(n_1 T_{s_1}, n_2 T_{s_2}, n T_s)$$

- n is a variable for time elapse and is an integer.
- For example if T_s = 1/30[sec], [redacted], which corresponds to time resolution is 30fps.
- Fs, the reciprocal of T_s F_s is called time sampling frequency.

Sample Exercise

- Let's think about two one-dimensional time signals of frequency F=1[Hz] and F'=5[Hz], $g_a(t)=\cos($[redacted]$t)$ and $g_a(t)=\cos($[redacted]$t)$. Please illustrate discrete signals obtained by sampling these signals with sampling interval $T_s=1/F_s=1/4$[sec] .

Answers

- Their sampled values are the same.
- Sampling time $t=nT_s$, and
  $g(n)=\cos(\pi n/2)=\cos(2\pi+\pi n/2)=g'(n)$
- Generally when $F'=F+kF_s$ (k is an integer), both of the sampled values become identical.

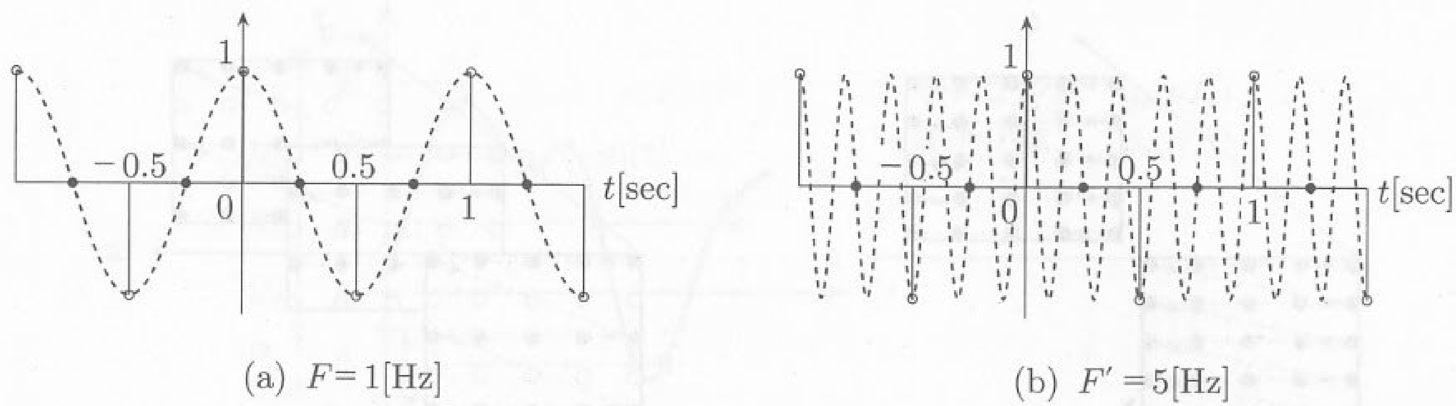


図 **1.5** 例題 1.2

[redacted](走査)

- Process to transform multi-dimensional signals to one dimensional signals.

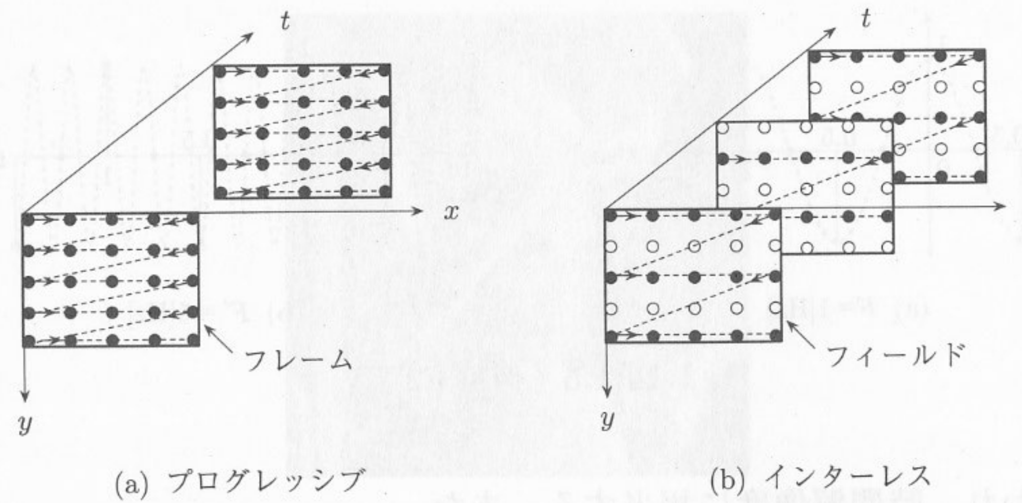


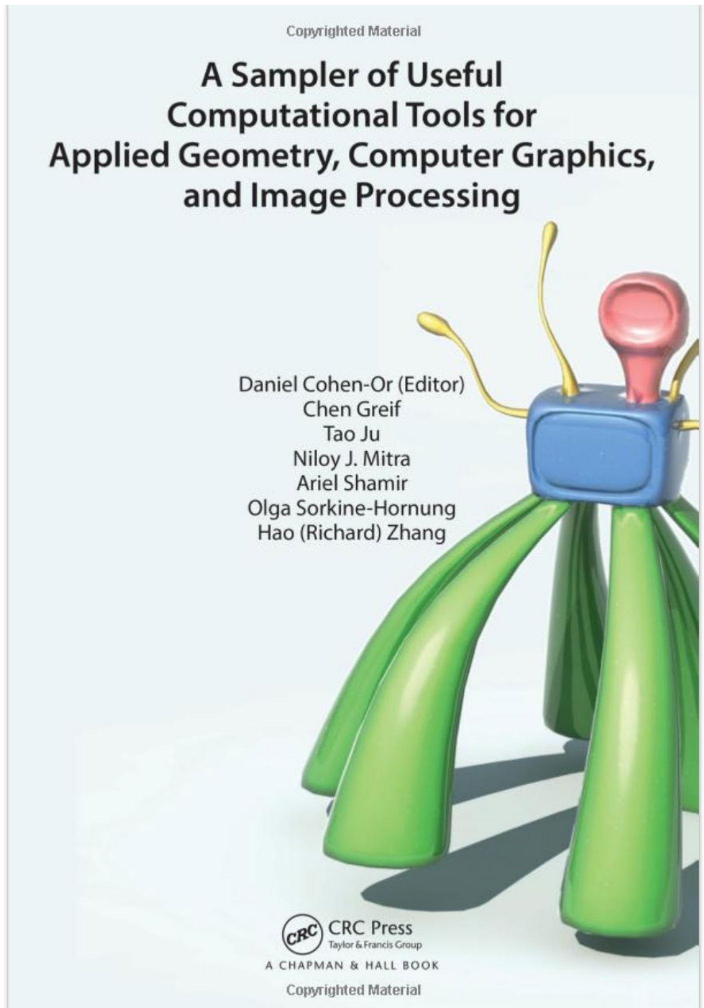
図 1.6　走査方式とサンプリング・パターン

- TV broadcasting uses [redacted] and movie files do [redacted].
- Prioritize time resolution or space resolution?

Summery

- Contents of course
- Image signals
  - Analog image
  - Digital image
- Sampling and quantization

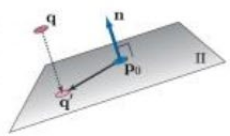
Additional topics



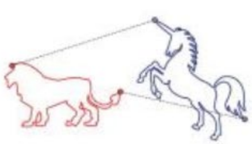
Additional topics

Book Contents

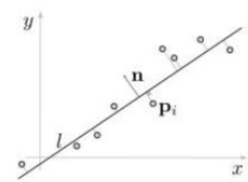
In the first chapter, we will familiarize ourselves with some basic geometric tools and see how we can put them to practical use to solve several geometric problems. Instead of describing the tools directly, we do it through an interesting discussion of two possible ways to approach the geometric problem at hand: we can employ our geometric intuition and use geometric reasoning, or we can directly formalize everything and employ our algebraic skills to write down and solve some equations. The discussion leads to a presentation of linear geometric elements (points, lines, planes), and the means to manipulate them in common geometric applications that we encounter, such as distances, transformations, projections and more.



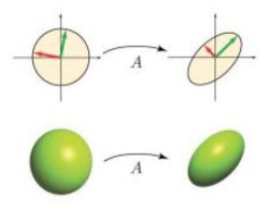
In this chapter, we will review basic linear algebra notions that we learned in a basic linear algebra course, including vector spaces, orthogonal bases, subspaces, eigenvalues and eigenvectors. However, our main goal here is to convince the readers that these notions are really useful. Furthermore, we will see the close relation between linear algebra and geometry. The chapter will be driven by an important tool called singular value decomposition (SVD), to which we will devote a separate full chapter. To understand what an SVD is, we first need to understand the notions of bases, eigenvectors, and eigenvalues and to refresh some fundamentals of linear algebra with examples in geometric context.



When dealing with real-world data, simple patterns can often be submerged in noise and outliers. In this chapter, we will learn about basic data fitting using the least-squares method, first starting with simple line fitting before moving on to fitting low-order polynomials. Beyond robustness to noise, we will also learn how to handle outliers and look at basic robust statics.



In this chapter, we introduce two related tools from linear algebra that have become true workhorses in countless areas of science: principal component analysis (PCA) and singular value decomposition (SVD). These tools are extremely useful in geometric modeling, computer vision, image processing, computer graphics, machine learning and many other applications. We will see how to decompose a matrix into several factors that are easy to analyze and reveal important properties of the matrix and hence the data, or the problem in which the matrix arises. As in the whole book, the presentation is rather light, emphasizing the main principles without excessive rigor.



Additional topics

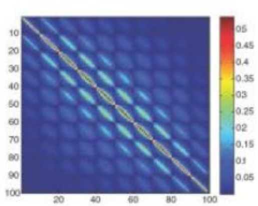
Chapter 5: Spectral Transform..........................63
Hao (Richard) Zhang

The use of signal transforms, such as the discrete Fourier or cosine transforms, is a classic topic in image and signal processing. In this chapter, we will learn how such transforms can be formulated and applied to the

processing of 2D and 3D geometric shapes. The key concept to take away is the use of eigenvectors of discrete Laplacian operators as basis vectors to define spectral transforms for geometry. We will show how the Laplacian operators can be defined for 2D and 3D shapes, as well as a few applications of spectral transforms including geometry smoothing, enhancement and compression.

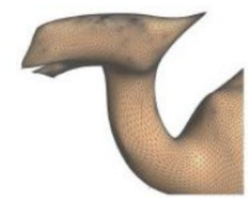
Chapter 6: Solution of Linear Systems..................81
Chen Greif

In the solution of problems discussed in this book, a frequent task that arises is the need to solve a linear system. Understanding the properties of the matrix associated with the linear system is critical for guaranteeing speed and accuracy of the solution procedure. In this chapter, we provide an overview of linear system solvers. We describe direct methods and iterative methods, and discuss important criteria for the selection of a solution method, such as sparsity and positive definiteness. Important notions such as pivoting and preconditioning are explained, and a recipe is provided that helps in determining which solver should be used.



Chapter 7: Laplace and Poisson..........................99
Daniel Cohen-Or and Gil Hoffer

In this chapter, we make use of the well-known equations of Laplace and Poisson. The two equations have an extremely simple form, and they are very useful in many diverse branches of mathematical physics. However, in this chapter, we will interpret them in the context of image processing. We will show some interesting image editing and geometric problems and how they can be solved by simple means using these equations.



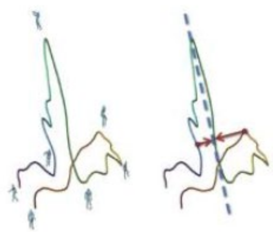
Chapter 8: Curvatures: A Differential Geometry Tool..117
Niloy J. Mitra and Daniel Cohen-Or

Local surface details, e.g., how "flat" a surface is locally, carry important information about the underlying object. Such information is critical for many applications in geometry processing, ranging from surface meshing, shape matching, surface reconstruction, scan alignment and detail-preserving deformation, to name only a few. In this chapter, we will cover the basics of differential geometry, particularly focusing on curvature estimates with some illustrative examples as an aid to geometry processing tasks.

Additional topics

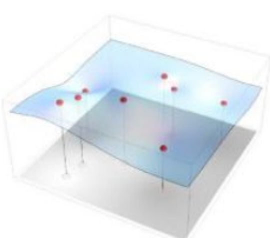
Chapter 9: Dimensionality Reduction 131
Hao (Richard) Zhang and Daniel Cohen-Or

In this chapter, we will learn the concept, usefulness, and execution of dimensionality reduction. Generally speaking, we will seek to reduce the dimensionality of a given data set, mapping high-dimensional data into a lower-dimensional space to facilitate visualization, processing, or inference. We will present and discuss only a sample of dimensionality reduction techniques and illustrate them using visually intuitive examples, including face recognition, surface flattening and pose normalization of 3D shapes.



Chapter 10: Scattered Data Interpolation 147
Tao Ju

In this chapter, we visit the classical mathematical problem of obtaining a continuous function over a spatial domain from data at a few sample locations. The problem comes up in various geometric modeling scenarios, a good example of which is surface reconstruction. The chapter will eventually introduce the very useful radial basis functions (RBFs) as a smooth and efficient solution to the interpolation problem. However, to understand their usefulness, the chapter will go through a succession of methods with increasing sophistication, including piecewise linear interpolation and Shepherd's method.



Chapter 11: Topology: How Are Objects Connected? 163
Niloy J. Mitra

In Chapter 8, we learned about local differential analysis of surfaces. In this chapter, we focus on global aspects. We will learn about what is meant by orientable surfaces or manifold surfaces. Most importantly, we will learn about the Euler characteristic, which links local curvature properties to global connectivity constraints, and comes up in a surprising range of applications.

Chapter 12: Graphs and Images 177
Ariel Shamir

Graphs play an important role in many computer science fields and are also extensively used in imaging and graphics. This chapter concentrates on image processing and demonstrates how images can be represented by a graph. This allows translating problems of analysis and manipulation of images to well-known graph algorithms. Specifically, we will show how segmentation of images can be solved using region-growing algorithms such as watershed or partitioning algorithms using graph cuts. We will also show how intelligently changing the size and aspect ratio of images and video can be solved using dynamic programming or graph cuts.

Additional topics

In this chapter, we will show an example of the usefulness of number theory, or at least one of its known theorems. We will discuss mappings of numbers to a lattice, a problem that has practical applications in systems that require simultaneous, conflict-free access to elements distributed in different memory modules. Such mappings are also called *skewing schemes* since they skew the trivial mapping from element to memory. To understand these mappings, we will visit the notions of relatively prime numbers, and the greatest common divisor (gcd).