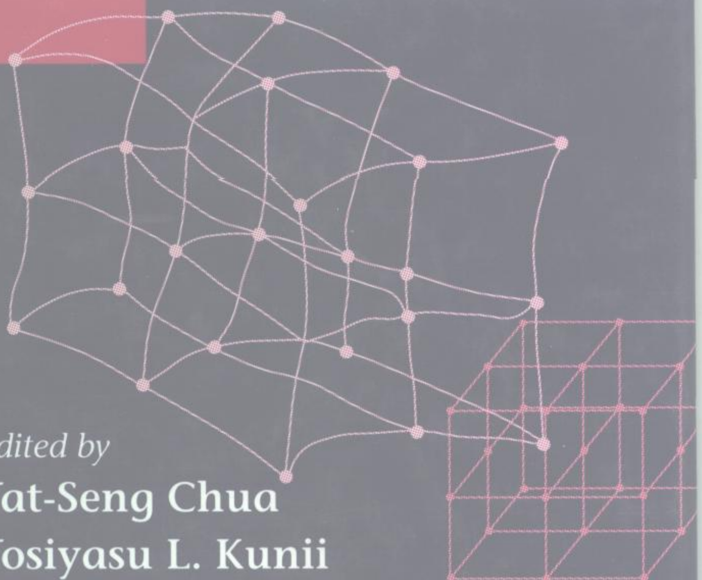
Proceedings of the First International Conference on Multi-Media Modeling

MULTIMEDIA MODELING



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Preface

The field of multimedia deals with the processing and integration of information of multiple medium types, including both the visual media (text, graphics, image and video), and audio media (speech, music and sound effects). These information can either be obtained from the sights and sounds of the real world or created synthetically with the aid of the computer. The synergy between computer graphics and multimedia means that the distinction between visual data derived from the real world and the synthetic world is becoming blurred. This has broadened the applications of multimedia from the traditional areas of information organization, presentation and learning, to the new fields of simulation and virtual reality.

Interest in multimedia has increased tremendously following the recent advances in multimedia technologies. These advances include improvements in compression, storage, database, communication and display technologies. These advancements have made it possible for us to build multimedia systems involving video that are capable of handling large quantities of information and which span communication networks. However, as with most fields in computer science, the software needed to drive useful applications has not been keeping pace with the development of technologies.

Central to the concept of multimedia is the idea of active medium. An active medium is one that the user can interact with to carry out useful operations such as the retrieval of further information. In an ideal information system, all information types should be active and can be accessed and interacted in a consistent way. Currently, we are a long way from this ideal. For instance, we know very little about the representation, indexing, interaction and retrieval of non-textual media, especially the image and video. This is because little is known about the primitive semantic units that characterize the contents of non-textual media. Signal analysis techniques can be explored to analyze the contents of these data for indexing and retrieving purposes. However, the fundamental problem of developing a consistent model to represent the contents of these media should also be addressed. To facilitate the modeling of higher level concepts using information of multiple medium types, new models must be developed to organize multimedia data in storage, integrate and synthesize them for presentation, and synchronize and transport them efficiently across the network. Lastly, the integration of multimedia and computer graphics to create a simulated world of real and synthetic objects also requires new techniques and models for its manipulation and modeling.

Multi-Media Modeling (MMM'93) conference is an attempt to provide a forum to discuss the issues of efficient representation, processing, interaction, integration, transmission and retrieval of multimedia information. It aims to bring together researchers from the fields of multimedia, computer graphics, computer vision, database, information retrieval and computer communication. The theme of the conference is modeling. In particular, the conference concentrates on the common modeling frameworks for integrating the diverse fields of multimedia information. It is hoped that the conference could play a positive role in influencing and guiding the research in this rich and exciting field. MMM'93 is only the beginning. Future conferences are planned on a biennial basis in November. The next MMM conference will be held in Singapore in November 1995.

This volume contains the technical papers presented at the MMM'93 conference held in Singapore on 9-12 November 1993. Altogether 21 technical papers are included in this volume. These include 3 invited papers, and 18 reviewed papers. The reviewed papers were selected, through peer review, from papers submitted from around the world. A rigorous reviewing process was carried out by expert reviewers in their respective fields. The papers selected are therefore of high quality. The countries represented in this volume include: Australia, France, Germany, Greece, Hong Kong, Japan, Korea, The Netherlands, Russia, Singapore, Sweden and Switzerland. Thus, there is wide international representation.

The papers are grouped into 10 chapters. They are: Visualization and Geometry Modeling, Multimedia Testbed and Computer Music, User Interface and Usability, Multimedia Data Model and Framework, Multimedia Authoring, Video Encoding and Indexing, JPEG Compression and Distribution, Networked Multimedia, Multimedia Synchronization, and Distributed Multimedia and Sound. These chapters cover most of the major issues of current research interests.

We are grateful to the authors for submitting the papers, and to the reviewers for their considerable efforts in reviewing the papers on time. We would also like to acknowledge the support of our sponsors and co-organizers for making this conference possible. Finally, special thanks are due to the conference organizing committee, and in particular, Mrs. Veronica Ho, for helping to put this conference together.

T.S. Chua
T.L. Kunii

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Chapter 1

Visualization and Geometry Modeling

Visualizing Highly Abstract Mathematical Concepts: a Case Study in Animation of Homology Groups

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Abstract

Visualization is a powerful means to understand the properties of objects for designing industrial products. Object visualization has been, however, mostly based on simple mathematical concepts such as vector fields and isosurfaces of functions.

This paper proposes a method to visualize a highly abstract mathematical concept: algebraic topology, particularly homology groups.

We present a system that visualizes the computational process of homology groups; i.e., computation of groups of cycles Z, groups of boundaries B, and then the homology groups as the quotient groups Z/B. The animation of homology exact sequences is provided to compute homology groups that are difficult to be obtained directly. Quotient groups are also visualized in the system.

Keywords: algebraic topology, exact sequence, homology theory, homology groups, simplicial complex

1 Introduction

Visualization is a powerful means to understand the properties of objects. We can obtain the overview of objects, and see where to examine the details. For example, it is difficult to detect the maximum values of functions from the equations, while it is easy to find them when we draw the graphs.

Visualization has been, however, mostly based on simple mathematical concepts such as vector fields or isosurfaces of functions. Abstract mathematical concepts such as groups and topological invariants have not yet been visualized.

This paper presents the visualization of abstract algebraic concept: algebraic topology. Algebraic topology is an area of topology where topological problems are transformed into algebraic problems by means of groups and homomorphisms. The basic purposes of topology are to determine whether two spaces are homeomorphic and to classify the shapes of objects. It is important to find the criteria of the classification, which are called the *topological invariants*(properties preserved under homeomorphisms). For example, connectedness and compactness are topological invariants.

A homology group is one of topological invariants in algebraic topology, i.e., it represents the topological structure of an object. If two spaces are the same in shape(homeomorphic), their homology groups are the same(isomorphic). Conversely, if homology groups of two spaces are not isomorphic, they cannot be homeomorphic. Intuitively speaking, given a natural number r ($r = 0, 1, 2, \ldots$), the r-dimensional homology group counts the number of "r-dimensional holes". For example, a zero-dimensional homology group counts the number of connected components(0-dimensional holes), an one-dimensional homology group counts the number of usual holes, and a two-dimensional homology group counts the number of closed spaces(2-dimensional holes).

Although a homology group is a powerful tool to represent the topological structure, it is abstract and hence it has been difficult to understand. We present a system that visualizes the computation of homology groups. Our system provides the algorithm animation of the computation. Algorithm animation [2, 6] is an area of visualizing abstract concepts. Algorithm animation has visualized simple algorithms such as sorting or graph algorithms. Here, we handle much more complicated algorithms.

The relative homology groups and homology exact sequences are useful when the homology groups is difficult to be computed directly. The system provides an animation that visualizes the process of computing homology groups through the homology exact sequence.

2 Mathematical Preliminaries

This section is devoted to the explanation of basic mathematical concepts and notations. Section *2.1* describes groups and homomorphisms. Homology theory is introduced in Section *2.2*. The algorithm of computing homology groups are presented in Appendix.

2.1 Basic Concepts on Groups and Homomorphisms

As stated before, the topological structure is represented by a group called the homology group. Here, we give the brief preliminaries to the theories of groups and homomorphisms.

2.1.1 Groups and Abelian Groups

For example, the set of integers with the addition operation is an abelian group(We often denote this group by $\boldsymbol{Z}$).

Formally, a *group* is a set G together with an operation $* : G \times G \to G$ which satisfies the following three conditions.

(1) *associativity* : $a * (b * c) = (a * b) * c, \;\; \forall a, b, c \in G$

(2) *existence of identity element* : There is an element $e \in G$ such that $a * e = e * a = a, \;\; \forall a \in G$.

(3) *existence of inverse elements* : There is an element $a^{-1} \in G$ for each element $a \in G$ such that $a * a^{-1} = a^{-1} * a = e$.

When the operation $*$ is commutative, i.e., $a * b = b * a \;\; \forall a, b \in G$, the group G is said to be *abelian*. In case of abelian groups, the identity element is often denoted by 0, and the inverse element of a is by $-a$.

2.1.2 Subgroups and Normal Subgroups

A subset H of a group G is called a *subgroup* of G if H is also a group together with the operation $*$ on G. Note that $a * b \in H, \;\; \forall a, b \in H$. For example, the set of multiples of a positive integer m with the addition operation is a subgroup of $\boldsymbol{Z}$. It is often denoted by $m\boldsymbol{Z}$.

If a subgroup N of a group G satisfies the condition $g * n * g^{-1} = n, \;\; \forall g \in G, \forall n \in N$, N is called a *normal subgroup* of G. Note that any subgroup of an abelian group G is a normal subgroup, since $g + n - g = n + g - g = n + 0 = n$ in G. For example, the group $m\boldsymbol{Z}$ is actually a normal subgroup of $\boldsymbol{Z}$.

2.1.3 Generators

Let x be an element of a group G. Now define

$$x^m = \begin{cases} \overbrace{x * x * \cdots * x}^{m \text{ times}}, & m > 0 \\ \overbrace{x^{-1} * x^{-1} * \cdots * x^{-1}}^{m \text{ times}}, & m < 0 \\ e(\text{the identity element}), & m = 0 \end{cases} .$$

The set of all integer powers of x:

$$\{\ldots, x^{-2}, x^{-1}, x^0, x^2, \ldots\}$$

is a subgroup of G and is denoted by $<x>$. This subgroup is called the *subgroup generated by* x. If $G = <x>$, G is called a *cyclic group*. For example, $\boldsymbol{Z}$ with addition is a cyclic group generated by 1 or -1.

Let $S = \{x_0, x_1, \ldots\}$ be a subset of a group G. The set $<S>$

$$\{x_0^{m_0} * x_1^{m_1} * \cdots \mid m_i \in \boldsymbol{Z}, i = 0, 1, \ldots\}$$

together with the operation of G is a subgroup of G and is called the *subgroup generated by* S. S is called a *set of generators* and an element of S is called a *generator*. If $S = \{x\}$, $<S>$ is simply written as $<x>$.

2.1.4 Homomorphisms

Let f be a mapping from a group G to a group H. Let us denote the operation of G and H by $*$ and $\times$ respectively. The mapping $f : G \to H$ is said to be a *homomorphism* if the relation

$$f(a * b) = f(a) \times f(b), \quad \forall a, b \in G$$

is satisfied. Note that f maps a subgroup of G to a subgroup of H. An injective(one to one) homomorphism is called a *monomorphism*, a surjective(onto) homomorphism is called an *epimorphism*, and a bijective(one to one and onto) homomorphism is called an *isomorphism*. Two groups G and H are said to be *isomorphic*, if there is an isomorphism between them.

The homomorphism f maps the whole group G to a subgroup of H, which is called the *image* of f. The following subset of G is a subgroup of G, and is called the *kernel* of f.

$$\text{kernel} f = \{x \mid x \in G, \text{ such that } f(x) = e_H \in H\},$$

where e_H is the identity element of H. Intuitively speaking, the kernel consists of the elements of G that "shrunk" to the "zero" by f.

2.1.5 Equivalence Relations, Equivalence Classes and Quotient Sets

Let S be a set. When a relation $\sim$ satisfies the following conditions, it is called an *equivalence relation.*

(1) *reflexive* : $a \sim a \ \forall a \in S$

(2) *symmetric* : If $a \sim b$ then $b \sim a, \ a, b \in S$.

(3) *transitive* : If $a \sim b$ and $b \sim c$ then $a \sim c, \ a, b, c \in S$.

For example, the congruence modulo m[¶] is an equivalent relation on $\boldsymbol{Z}$.

Let a be an element of S. A subset $[a]$ of S

$$\{x \mid x \in S, x \sim a\}$$

is called the *equivalence class* of a relative to $\sim$. Note that if $a \sim b$ then $[a] = [b]$. The reverse is also true, i.e., if $[a] = [b]$ then $a \sim b$.

Let $P(S)$ be the set of all equivalence classes of S. This set $P(S)$ is often denoted by $S/\sim$, and is called the quotient set of S relative to $\sim$. For example, $\boldsymbol{Z}$ is divided into m equivalence classes by the congruence modulo m, i.e., $\boldsymbol{Z}/(=_{\text{mod } m}) = \{[0], [1], \ldots, [m-1]\}$.

2.1.6 Quotient Groups

Let H be a subgroup of a group G and $\sim$ be the relation on G such that,

$$a \sim b \ \ iff \ \ a = b * h, \ \ \exists h \in H.$$

This relation is an equivalent relation. The quotient set $G/\sim$ together with the operation of G forms a group when H is a normal subgroup of G. This group is called the *quotient group* of G by H, and is denoted by G/H. For example, $\boldsymbol{Z}_m = \boldsymbol{Z}/m\boldsymbol{Z}$ is the quotient group of $\boldsymbol{Z}$ by $m\boldsymbol{Z}$. $\boldsymbol{Z}_m$ is a cyclic group generated by $[x]$, where x and m are mutually prime.

2.1.7 Finitely Generated Abelian Groups

An abelian group G is called *finitely generated* if every element of G is given by a linear combination of elements in a finite subset S of G. S is called a *system of generators.* If a system of generators S of G is linearly independent, G is called a *free abelian group* and S is called a *basis* of G.

Let A be a free abelian group with a basis $S = \{s_1, s_2, \ldots, s_m\}$, B be a subgroup of A with a basis $R = \{r_1, r_2, \ldots, r_n\} (n \leq m)$, and G be the quotient group A/B. Here, we denote the finitely generated abelian group G by

$$G = [S : R] = [s_1, s_2, \ldots, s_m : r_1, r_2 \ldots, r_n].$$

[¶] Two integers a, b satisfy $a = b (\text{mod } m) \ \ iff \ \ a - b = pm, \ \ \exists p \in \boldsymbol{Z}$.

This representation can be transformed to the following normal form [1],

$$G = [u_1, \ldots, u_t, u_{t+1}, \ldots, u_{t+r} : \gamma_1 u_1, \ldots, \gamma_t u_t]$$

where $\gamma_i \geq 2(1 \leq i \leq t)$ and γ_{i+1} is a multiple of $\gamma_i(1 \leq i < t)$. This result shows that G is isomorphic to the direct sum of abelian groups,

$$\boldsymbol{Z}_{\gamma_1} \oplus \ldots \oplus \boldsymbol{Z}_{\gamma_t} \oplus \overbrace{\boldsymbol{Z} \oplus \ldots \oplus \boldsymbol{Z}}^{r}.$$

This direct sum decomposition is called $(r : \gamma_1, \ldots, \gamma_t)$–type normal direct sum decomposition of finitely generated abelian group G. The number r is called *rank* of G, and $\gamma_1, \ldots, \gamma_t$ are called *torsion coefficients* of G. The normal direct sum decomposition is unique for each group, that is, two finitely generated abelian groups G and H are isomorphic if they have the same normal direct sum decomposition.

2.2 Homology Theory of Simplicial Complexes

A figure such as a polygon and a polyhedron can be decomposed into triangles. We can understand the topological structure of the figure from the patterns of connections of triangles in this decomposition. The homology theory of simplicial complexes is the generalization of this idea; the topological structure of a figure(simplicial complex) is expressed by abelian groups that indicate the connectivity of simplexes in the figure(readers may refer to ch.6 of [4] for background of homology theory).

Intuitively speaking, the r-dimensional homology group of a figure measures the number of "r-dimensional holes" in it. For example, a zero-dimensional hole corresponds to a connected component, an one-dimensional hole corresponds to a loop(an usual hole), and a two-dimensional hole corresponds to a closed space. We give an example of the computation of homology groups of a Möbius strip in the Appendix.

2.2.1 Simplexes and Simplicial Complexes

Definition (*Simplexes*) An *m-simplex* is the set

$$S = \{\sum_i t_i p_i \mid \forall t_i \geq 0, \sum_i t_i = 1(0 \leq i \leq m)\}$$

where $p_0, \ldots p_m$ are $m+1$ points in $\boldsymbol{R}^n(m \leq n)$, and the vectors $p_1 - p_0, \ldots, p_m - p_0$ are linearly independent. For example, a 0-simplex is a point, a 1-simplex is a line segment, a 2-simplex is a triangle, and a 3-simplex is a tetrahedron. The number m is called the dimension of the simplex S. The k-simplex consisting of a set of vertices $\{p_{i_0}, p_{i_1}, \ldots, p_{i_k}\}(k \leq m)$ is called a *k-face* of the simplex S.

Suppose there is an ordering of the vertices of a simplex $S = (p_0 p_1 \ldots p_m)$. It is said that a simplex $S' = (p_{i_0} p_{i_1} \ldots p_{i_m})$ has the same orientation with the simplex S, if the permutation

$$\begin{pmatrix} 0 & 1 & \dots & m \\ i_0 & i_1 & \dots & i_m \end{pmatrix}$$

is an even permutation. On the other hand, if this permutation is an odd permutation, the simplex S' is said to have the opposite orientation with the simplex S, and is denoted by $-S$. Hence there are two *oriented simplex* S and $-S$ for each m-simplex $S\,(m > 0)$.

Definition (*Simplicial Complexes*) A finite set K of simplexes is called a *simplicial complex*, if the following two conditions are satisfied.

(1) For any simplex σ in K, any face of σ belongs to K.

(2) For any two simplexes σ, σ' in K, the intersection of σ and σ' is empty or a face of both simplexes.

For example, Figure 1(a) is a simplicial complex while Figure 1(b) is not. The dimension of a simplicial complex K is defined to be n, if there is an n-simplex and no $(n+1)$-simplex in K. A set $L(\subset K)$ is called subcomplex of K, if L satisfies the condition (1) above.

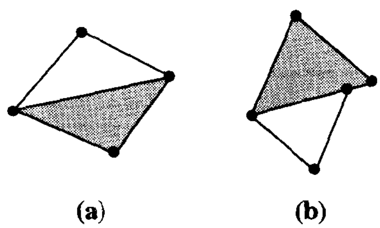

Figure 1: A simplicial complex and a non simplicial complex

2.2.2 Homology Groups of Simplicial Complexes

Assume K is a simplicial complex of dimension m. A free abelian group generated by all r-simplexes$(0 \leq r \leq m)$ in the simplicial complex K is called the *r-dimensional chain group* of K, and is denoted as $C_r(K)$. An element of an r-dimensional chain group is called an *r-chain*. We define $C_r(K) = 0$ for $r > m$ and $r < 0$.

For an r-simplex $\sigma = (p_0 \dots p_r)$ $r > 0$, the *boundary* of σ is defined as follows,

$$\partial_r(\sigma) = \sum_{i=0}^{r} (-1)^i (p_0 p_1 \dots \hat{p}_i \dots p_r),$$