Activity Report 2012

Team CAD

Computer Aided Design

RESEARCH CENTER
Paris - Rocquencourt

THEME
Computational models and simulation

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Team CAD

Keywords: Geometry Modeling, Curves And Surfaces, Visualization, Rendering, Image Processing

Creation of the Team: January 01, 2009 .

1. Members

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2. Overall Objectives

2.1. Overall Objectives

Geometry Modeling has a dramatic impact on the way designer and engineer work. In the industry, sketch and design, structural and mechanical engineering, aerodynamic studies, marketing, project review, pilot training, ergonomic studies or maintenance operations, all these works are based on geometric models and numerical simulations on these models. In Computer Aided Systems, the mathematical representation of curves and surfaces are based on parametric surfaces. This representation is very practical for the designer. The designer can create curves and surfaces very easily with control points and basis functions that influence the domain of control points. However, there are a lot of theoretical and practical computational problems with these surfaces. Our overall objective is to find new ways to address these problems.

In 2010, a Professor (CASIA) and two Associated Professors (Tsinghua and CASIA), previously students of Prof. Jean-Claude Paul in France, joined CAD. They worked in Computer Graphics and had some results in Computational Photography, Rendering and Computer Animation. In the future, the Group aims to work in the direction of using Machine Learning methods to solve Computer Graphics problems, with applications in *Design*.

3. Scientific Foundations

3.1. Geometry continuity and ε Geometry Continuity

The mathematical background of parametric surfaces is Differential Geometry. In differential geometry, Riemann (1826 1866), Shiing-Shen Chern (1911 2004), continuities play a very important kernel role. In 1980s, more and more engineering design using geometry modeling softwares found the problems of the parametric continuities. And the order of the parametric continuity depends on how the curve is parameterized. To day, engineers and scientists try to find a kind of continuities, which are the intuitive intrinsic properties of curves and surfaces, and the orders of the continuities are independent of the parameterization.

G-Continuity could be defined as the smoothness properties of a curve or a surface that are more than its order of differentiability. This problem is complex and progress in this domain is very slow. We proposed new ways to make through the bottleneck. Furthermore, we also wanted to fill the gap between the traditional mathematics and modern computer science. Hence, we developed the theories of epsilon-geometry continuities to accommodate the representation and the rounding errors of float-point arithmetic, and design new geometric modeling operators under the constraints of epsilon-geometry continuities.

3.2. Two main challenges in Computer Aided Design

3.2.1. Robustness tolerance, error control

Based on this theoretical contribution, we also proposed several elegant solutions to the most important challenges in Computer Aided Design (see Lees A Piegl. "Ten challenges in Computer-Aided-Design". Jal of CAD 2005. 37 (4): 461-470): robustness, tolerances, error control, geometric arrangement, beautification and modelling of complex shapes. During CAD processes one uses a myriad of tolerances, many of which are not directly related to the actual manufacturing process. Some interesting questions here include: What are the most relevant machining tolerances? How to set the army of computational tolerances, e.g. those of systems of equations, to guarantee machining within the required accuracy? How tolerances in different spaces, e.g. in model space and in parameter space, are related. Numerical instabilities also account for the majority of computational errors in commercial CAD systems.

The problems related to robustness haunt every programmer who has ever worked on commercial systems. Fixing numerical bugs can be very frustrating, and often times results in patching up the code simply because no solution exists to remedy the problem.

3.2.2. Geometry beautification, Geometry operators and Shape generation

Although geometric uncertainties are related to robustness and tolerance, there are a number of extra issues well worth deeper investigations. Geometric arrangements are full of special cases. The most notable ones are: cases of touch, overlapping, containment, etc.; cases of parallelism, perpendicularity, coincidence, etc.; axes of symmetrical data, data clustering, dense or sparse data, etc.; cases of degeneracy, discontinuity, inconsistencies, etc.; problems with cracks, excess material, lack of detail, etc. In just about any code that deals with geometry, the number of special cases is significantly larger than the general ones. Data explosion is the result of careless selection of the methods, e.g. parameter space-based sampling, and improper implementation, e.g. recursive algorithms. Some of the relevant issues are: sampling: over sampling, sampling in incorrect places, etc; procedural definitions, e.g. lofting a large set of curves or merging surfaces may result in an explosion of control points.

Furthermore, although CAD processes are supposed to produce valid and "made to order" models, the reality is that most (if not all) models are rough and require post-processing, i.e. beautification. Some of the most frequently needed tasks are: removing unwanted edges, corners, cracks, etc.; removing bumps, oscillations, curvature extremes, etc.; healing incorrect models, e.g. removing holes in triangulations; smoothing, fairing, re-shaping, etc.

3.3. Computer Graphics

In Computer Graphics, objectives were to prove the capability of the team to address some topics as Computational Photography, Rendering and Computer Animation. Work in Progress in these topics are described in the following chapter.

4. Application Domains

4.1. Introduction

Our scientific results in geometry have been tested in Aircraft industry, Ceramic industry, N-C simulation, and Computer Graphics as well.

4.2. Geometry

The cooperation with EADS, based on our new B-Spline surface formulation, is very promising, both for complex shape modelling and numerical simulations. Tolerance problems are currently studied in the sino-french Tsinghua PLM Center (supported by Dassault System).

Furthermore, this project also allowed to promoting several Associated Professors and Post Doctors in Chinese and French Research Institutes.

4.3. Computer Graphics

In Computer Graphics, our work in Computer Animation (fluid dynamics) has been tested in the Mr. Zhiyi Zhang's company.

5. Software

5.1. Softwares

1. Tsinghua University, Inria. Software: Modeling Software 2010.
2. Inria, Tsinghua University. Prototype: Tool for Curve Projection on Surfaces 2011.
3. Tsinghua University & Inria. Software: Spline Software Tool 2012.
4. Inria, Tsinghua University. Software: Mesh Segmentation Tool 2012.

We have developed various prototype software but, currently, they are not distributed and used only within the project. Regarding software, we know (see the last LIAMA evaluation report) that we should consider disseminating some of its codes more widely. Using established libraries may improve the impact of some of the results. We did not do it, due to the fast turn over of students in the Chinese team and the lack of Manpower and know-how in the French part.

6. New Results

6.1. Geometry Modeling and Processing

6.1.1. Relaxed lightweight assembly retrieval using vector space model

Participants: Kai-Mo Hu, Bin Wang, Jun-Hai Yong, Jean-Claude Paul.

Assembly searching technologies are important for the improvement of design reusability. However, existing methods require that assemblies possess high-level information, and thus cannot be applied in lightweight assemblies. In this paper, we propose a novel relaxed lightweight assembly retrieval approach based on a vector space model (VSM). By decomposing the assemblies represented in a watertight polygon mesh into bags of parts, and considering the queries as a vague specification of a set of parts, the resilient ranking strategy in VSM is successfully applied in the assembly retrieval. Furthermore, we take the scale-sensitive similarities between parts into the evaluation of matching values, and extend the original VSM to a relaxed matching framework. This framework allows users to input any fuzzy queries, is capable of measuring the results quantitatively, and performs well in retrieving assemblies with specified characteristics. To accelerate the online matching procedure, a typical parts based matching process, as well as a greedy strategy based matching algorithm is presented and integrated in the framework, which makes our system achieve interactive performance. We demonstrate the efficiency and effectiveness of our approach through various experiments on the prototype system. [19]

6.1.2. Calculating Jacobian coefficients of primitive constraints with respect to Euler parameters

Participants: Hai-Chuan Song, Jun-Hai Yong.

It is a fundamental problem to calculate Jacobian coefficients of constraint equations in assembly constraint solving because most approaches to solving an assembly constraint system will finally resort to a numerical iterative method that requires the first-order derivatives of the constraint equations. The most-used method of deriving the Jacobian coefficients is to use virtual rotation which is originally presented to derive the equations of motion of constrained mechanical systems. However, when Euler parameters are adopted as the state variables to represent the transformation matrix, using the virtual rotation will yield erroneous formulae of Jacobian coefficients. The reason is that Euler parameters are incompatible with virtual rotation. In this paper, correct formulae of Jacobian coefficients of geometric constraints with respect to Euler parameters are presented in both Cartesian coordinates and relative generalized coordinates. Experimental results show that our proposed formulae make Newton-Raphson iterative method converge faster and more stable. [22]

6.1.3. An extended schema and its production rule-based algorithms for assembly data exchange using IGES

Participants: Kai-Mo Hu, Bin Wang, Jun-Hai Yong.

Assembly data exchange and reuse play an important role in CAD and CAM in shortening the product development cycle. However, current CAD systems cannot transfer mating conditions via neutral file format, and their exported IGES files are heterogeneous. In this paper, a schema for the full data exchange of assemblies is presented based on IGES. We first design algorithms for the pre-and-post processors of parts based on solid model, in which the topologies are explicitly specified and will be referred by mating conditions, and then extend the IGES schema by introducing the Associativity Definition Entity and Associativity Instance Entity defined in IGES standard, so as to represent mating conditions. Finally, a production rule-based method is proposed to analyze and design the data exchange algorithms for assemblies. Within this schema, the heterogeneous representations of assemblies exported from different CAD systems can be processed appropriately, and the mating conditions can be properly exchanged. Experiments on the prototype system verify the robustness, correctness, and flexibility of our schema. [18]

6.1.4. Robust shape normalization of 3D articulated volumetric models

Participants: Yu-Shen Liu, Jun-Hai Yong, Jean-Claude Paul.

3D shape normalization is a common task in various computer graphics and pattern recognition applications. It aims to normalize different objects into a canonical coordinate frame with respect to rigid transformations containing translation, rotation and scaling in order to guarantee a unique representation. However, the conventional normalization approaches do not perform well when dealing with 3D articulated objects.

To address this issue, we introduce a new method for normalizing a 3D articulated object in the volumetric form. We use techniques from robust statistics to guide the classical normalization computation. The key idea is to estimate the initial normalization by using implicit shape representation, which produces a novel articulation insensitive weight function to reduce the influence of articulated deformation. We also propose and prove the articulation insensitivity of implicit shape representation. The final solution is found by means of iteratively reweighted least squares. Our method is robust to articulated deformation without any explicit shape decomposition. The experimental results and some applications are presented for demonstrating the effectiveness of our method. [24]

6.1.5. G^1 continuous approximate curves on NURBS surfaces

Participant: Jun-Hai Yong.

Curves on surfaces play an important role in computer aided geometric design. In this paper, we present a parabola approximation method based on the cubic reparameterization of rational Bézier surfaces, which generates G^1 continuous approximate curves lying completely on the surfaces by using iso-parameter curves of the reparameterized surfaces. The Hausdorff distance between the approximate curve and the exact curve is controlled under the user-specified tolerance. Examples are given to show the performance of our algorithm. [28]

6.1.6. The IFC-based path planning for 3D indoor spaces

Participant: Yu-Shen Liu.

Path planning is a fundamental problem, especially for various AEC applications, such as architectural design, indoor and outdoor navigation, and emergency evacuation. However, the conventional approaches mainly operate path planning on 2D drawings or building layouts by simply considering geometric information, while losing abundant semantic information of building components. To address this issue, this paper introduces a new method to cope with path planning for 3D indoor space through an IFC (Industry Foundation Classes) file as input. As a major data exchange standard for Building Information Modeling (BIM), the IFC standard is capable of restoring both geometric information and rich semantic information of building components to support lifecycle data sharing. The method consists of three main steps: (1) extracting both geometric and semantic information of building components defined within the IFC file, (2) discretizing and mapping the extracted information into a planar grid, (3) and finally finding the shortest path based on the mapping for path planning using Fast Marching Method. The paper aims to process different kinds of building components and their corresponding properties to obtain rich semantic information that can enhance applications of path planning. In addition, the IFC-based distributed data sharing and management is implemented for path planning. The paper also presents some experiments to demonstrate the accuracy, efficiency and adaptability of the method. Video demonstration is available from http://cgcad.thss.tsinghua.edu.cn/liuyushen/ifcpath/. [20]

6.1.7. Recovering Geometric Detail by Octree Normal Maps

Participants: Bin Wang, Jean-Claude Paul.

This paper presents a new approach for constructing normal maps that capture high-frequency geometric detail from dense models of arbitrary topology and are applied to the simplified version of the same models generated by any simplification method to mimic the same level of detail. A variant of loose octree scheme is used to optimally calculate the mesh normals. A B-spline surface fitting based method is employed to solve the issue of thin plate. A memory saving Breadth-First Search (BFS) order construction is designed. Furthermore, a speedup scheme that exploits access coherence is used to accelerate filtering operation. The proposed method can synthesize good quality images of models with extremely high number of polygons while using much less memory and render at much higher frame rate. [31]

6.1.8. An improved example-driven symbol recognition approach in engineering drawings

Participants: Hui Zhang, Ya-Mei Wen.

In this paper, an improved example-driven symbol recognition algorithm is proposed for CAD engineering drawings. First, in order to represent the structure of symbols more clearly and simply, we involve the text entity as one of the basic elements and redefine the relation representation mechanism, which is the foundation for the following algorithms. Then, the structure graph and a constrained tree can be established automatically for the target symbol, using the knowledge acquisition algorithm. In this process, the highest priority element is considered as the key feature, which will be regarded as the root node of the tree. The sequence of breadth first traveling will be recorded to be the recognition rule and saved in the symbol library. In the recognition process, the nodes with the same type as the key features can be located first in the drawing. Unnecessary matching calculations would be greatly reduced because of the accurate location. The other elements around, which satisfy the topology structure of the constrained tree, will be found next. The target symbol is recognized if all of the elements and constraints in the tree are found. Moreover, an extra preprocessing analysis approach is proposed to address repeat modes in a symbol. Thus, similar symbols can be recognized by one rule. We evaluate the proposed approach on the GREC databases and the real engineering drawings. The experimental results validate its effectiveness and efficiency. [17]

6.1.9. 3DMolNavi: A web-based retrieval and navigation tool for flexible molecular shape comparison

Participants: Yu-Shen Liu, Jean-Claude Paul.

Many molecules of interest are flexible and undergo significant shape deformation as part of their function, but most existing methods of molecular shape comparison treat them as rigid shapes, which may lead to incorrect measure of the shape similarity of flexible molecules. Currently, there still is a limited effort in retrieval and navigation for flexible molecular shape comparison, which would improve data retrieval by helping users locate the desirable molecule in a convenient way. To address this issue, we develop a web-based retrieval and navigation tool, named 3DMolNavi, for flexible molecular shape comparison. This tool is based on the histogram of Inner Distance Shape Signature (IDSS) for fast retrieving molecules that are similar to a query molecule, and uses dimensionality reduction to navigate the retrieved results in 2D and 3D spaces. We tested 3DMolNavi in the Database of Macromolecular Movements (MolMovDB) and CATH. Compared to other shape descriptors, it achieves good performance and retrieval results for different classes of flexible molecules. The advantages of 3DMolNavi, over other existing softwares, are to integrate retrieval for flexible molecular shape comparison and enhance navigation for user's interaction. [23]

6.1.10. Manifold-ranking based retrieval using k-regular nearest neighbor graph

Participants: Bin Wang, Kai-Mo Hu, Jean-Claude Paul.

Manifold-ranking is a powerful method in semi-supervised learning, and its performance heavily depends on the quality of the constructed graph. In this paper, we propose a novel graph structure named k-regular nearest neighbor (k-RNN) graph as well as its constructing algorithm, and apply the new graph structure in the framework of manifold-ranking based retrieval. We show that the manifold-ranking algorithm based on our proposed graph structure performs better than that of the existing graph structures such as k-nearest neighbor (k-NN) graph and connected graph in image retrieval, 2D data clustering as well as 3D model retrieval. In addition, the automatic sample reweighting and graph updating algorithms are presented for the relevance feedback of our algorithm. Experiments demonstrate that the proposed algorithm outperforms the state-of-the-art algorithms. [25]

6.2. Computer Graphics

6.2.1. Content-Based Color Transfer

Participants: Fuzhang Wu, Weiming Dong, Yan Kong, Xing Mei, Jean-Claude Paul, Xiaopeng Zhang.

This paper presents a novel content-based method for transferring the colour patterns between images. Unlike previous methods that rely on image colour statistics, our method puts an emphasis on high-level scene content analysis. We first automatically extract the foreground subject areas and background scene layout from the scene. The semantic correspondences of the regions between source and target images are established. In the second step, the source image is re-coloured in a novel optimization framework, which incorporates the extracted content information and the spatial distributions of the target colour styles. A new progressive transfer scheme is proposed to integrate the advantages of both global and local transfer algorithms, as well as avoid the over-segmentation artefact in the result. Experiments show that with a better understanding of the scene contents, our method well preserves the spatial layout, the colour distribution and the visual coherence in the transfer process. As an interesting extension, our method can also be used to re-colour video clips with spatially-varied colour effects. [26]

6.2.2. Large-scale forest rendering: Real-time, realistic, and progressive

Participants: Xiaopeng Zhang, Weiming Dong.

Real-time rendering of large-scale forest landscape scenes is important in many applications, such as video games, Internet graphics, and landscape and cityscape scene design and visualization. One challenge in the field of virtual reality is transferring a large-scale forest environment containing plant models with rich geometric detail through the network and rendering them in real time. We present a new framework for rendering large-scale forest scenes realistically and quickly that integrates extracting level of detail (LOD) tree models, rendering real-time shadows for large-scale forests, and transmitting forest data for network applications. We construct a series of LOD tree models to compress the overall complexity of the forest in view-dependent forest navigation. A new leaf phyllotaxy LOD modeling method is presented to match leaf models with textures, balancing the visual effect and model complexity. To progressively render the scene from coarse to fine, sequences of LOD models are transferred from simple to complex. The forest can be rendered after obtaining a simple model of each tree, allowing users to quickly see a sketch of the scene. To improve client performance, we also adopt a LOD strategy for shadow maps. Smoothing filters are implemented entirely on the graphics processing unit (GPU) to reduce the shadows' aliasing artifacts, which creates a soft shadowing effect. We also present a hardware instancing method to render more levels of LOD models, which overcomes the limitation of the latest GPU that emits primitives into only a limited number of separate vertex streams. Experiments show that large-scale forest scenes can be rendered with smooth shadows and in real time. [14]

6.2.3. Fast Multi-Operator Image Resizing and Evaluation

Participants: Weiming Dong, Xiaopeng Zhang, Jean-Claude Paul.

Current multi-operator image resizing methods succeed in generating impressive results by using image similarity measure to guide the resizing process. An optimal operation path is found in the resizing space. However, their slow resizing speed caused by inefficient computation strategy of the bidirectional patch matching becomes a drawback in practical use. In this paper, we present a novel method to address this problem. By combining seam carving with scaling and cropping, our method can realize content-aware image resizing very fast. We define cost functions combing image energy and dominant color descriptor for all the operators to evaluate the damage to both local image content and global visual effect. Therefore our algorithm can automatically find an optimal sequence of operations to resize the image by using dynamic programming or greedy algorithm. We also extend our algorithm to indirect image resizing which can protect the aspect ratio of the dominant object in an image. [16]

6.2.4. Easy modeling of realistic trees from freehand sketches

Participant: Xiaopeng Zhang.

Creating realistic 3D tree models in a convenient way is a challenge in game design and movie making due to diversification and occlusion of tree structures. Current sketch-based and image-based approaches for fast tree modeling have limitations in effect and speed, and they generally include complex parameter adjustment, which brings difficulties to novices. In this paper, we present a simple method for quickly generating various 3D tree models from freehand sketches without parameter adjustment. On two input images, the user draws strokes representing the main branches and crown silhouettes of a tree. The system automatically produces a 3D tree at high speed. First, two 2D skeletons are built from strokes, and a 3D tree structure resembling the input sketches is built by branch retrieval from the 2D skeletons. Small branches are generated within the sketched 2D crown silhouettes based on self-similarity and angle restriction. This system is demonstrated on a variety of examples. It maintains the main features of a tree: the main branch structure and crown shape, and can be used as a convenient tool for tree simulation and design. [21]

6.2.5. Real-time ink simulation using a grid-particle method

Participants: Shibiao Xu, Xing Mei, Weiming Dong, Xiaopeng Zhang.

This paper presents an effective method to simulate the ink diffusion process in real time that yields realistic visual effects. Our algorithm updates the dynamic ink volume using a hybrid grid-particle method: the fluid velocity field is calculated with a low-resolution grid structure, whereas the highly detailed ink effects are controlled and visualized with the particles. To facilitate user interaction and extend this method, we propose a particle-guided method that allows artists to design the overall states using the coarse-resolution particles and to preview the motion quickly. To treat coupling with solids and other fluids, we update the grid-particle representation with no-penetration boundary conditions and implicit interaction conditions. To treat moving "ink-emitting" objects, we introduce an extra drag-force model to enhance the particle motion effects; this force might not be physically accurate, but it proves effective for producing animations. We also propose an improved ink rendering method that uses particle sprites and motion blurring techniques. The simulation and the rendering processes are efficiently implemented on graphics hardware at interactive frame rates. Compared to traditional fluid simulation methods that treat water and ink as two mixable fluids, our method is simple but effective: it captures various ink effects, such as pinned boundaries and filament patterns, while still running in real time, it allows easy control of the animation, it includes basic solid-fluid interactions, and it can address multiple ink sources without complex interface tracking. Our method is attractive for animation production and art design.

6.2.6. Image zooming using directional cubic convolution interpolation

Participant: Weiming Dong.

Image-zooming is a technique of producing a high-resolution image from its low-resolution counterpart. It is also called image interpolation because it is usually implemented by interpolation. Keys' cubic convolution (CC) interpolation method has become a standard in the image interpolation field, but CC interpolates indiscriminately the missing pixels in the horizontal or vertical direction and typically incurs blurring, blocking, ringing or other artefacts. In this study, the authors propose a novel edge-directed CC interpolation scheme which can adapt to the varying edge structures of images. The authors also give an estimation method of the strong edge for a missing pixel location, which guides the interpolation for the missing pixel. The authors' method can preserve the sharp edges and details of images with notable suppression of the artefacts that usually occur with CC interpolation. The experiment results demonstrate that the authors'method outperforms significantly CC interpolation in terms of both subjective and objective measures. [30]

7. Bilateral Contracts and Grants with Industry

7.1. EADS

We cooperate with EADS on geometric representation and FEM.

7.2. CAS-BEGCL Imaging Technology Corporation

We cooperate with CAS-BEGCL Imaging Technology Corporation on fluid simulation, object deformation and realistic rendering.

7.3. ANR/ NSFC AND SYSTEM@TIC: 2010-2013

The objectives of these Programs address Geometry Modeling and Computing, mainly Robustness and Tolerance as well as Geometric Uncertainties.

8. Partnerships and Cooperations

8.1. International Initiatives

8.1.1. Inria Associate Teams

CAD is an Inria/Tsinghua University team related to LIAMA (China).

8.1.2. Participation In International Programs

We attend an international program of National Natural Science Foundation of China from 2010 to 2013.

Floating Point continuity clearly is a pioneer effort to solving a well-known unsolved problem. Up to now, almost all geometric modeling tool kits are based on traditional mathematics. They ignore the fact that computers can only represent a finite set of real numbers and simply use the formula $(a - \varepsilon < b)$ and $(b < a + \varepsilon)$ to compare whether two real numbers a and b are equal to each other or not. In the way, it becomes a very hard problem how to choose the proper value i.e., the precision is often out of control in geometric modeling tool kits although few documents report such the fact. This problem is very difficult. We also explore some formal methods and applied them to geometric algorithms. It seems to be an interesting research avenue. Finally, we also plan to study tolerances problem more carefully with CAD/CAM experts, because many of tolerances are not only directly related to the actual manufacturing process.

The central challenge with spline surfaces is to control their continuity when multiple patches join and to enable different types of sharpness. We are especially excited by a new result that addresses a central problem with spline modeling that has been open for five decades: the variation of continuity across a patch. This is needed, for example, when a crease forms in a smooth area. Because spline surfaces are modeled using a (mostly separable) tonsorial product of polynomial bases, it is hard to have a different level of continuity on two opposite edges of a patch. We proposed a particularly elegant solution to this challenge by smoothly varying the parametric location of the spline knots. This allows the curve to transition from a configuration where knots overlap (sharp C^1 discontinuity) to a configuration where they are distinct (fully continuous surface). We think that this work will have a large impact on CAD-CAM. Moreover, we speculate that our new geometric representation could be good candidates for better solving numerical simulation (PDEs) problems.

9. Dissemination

9.1. Teaching - Supervision - Juries

9.1.1. Teaching

Pr. Jean-Claude Paul, Pr. Jun-Hai Yong, Dr. Bin Wang and Dr. Hui Zhang teach at Tsinghua University. Dr. Hui Zhang is the Dean of the Scool of Software Teaching Program.

Master : Pr. Xiaopeng Zhang and Dr. Weiming Dong teach at Graduate University of Chinese Academy of Sciences.

10. Bibliography

Major publications by the team in recent years

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