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Geometric Modelling

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Report

of the 1st Dagstuhl Seminar on

Geometric Modelling

July, 1 - 5, 1991

Organized by :

Gerald Farin (Arizona State University)
Hans Hagen (Universität Kaiserslautern)
Hartmut Noltemeier (Universität Würzburg)

The first Dagstuhl - seminar on Geometric Modelling was organized by Gerald Farin (Arizona State University), Hans Hagen (Universität Kaiserslautern) and Hartmut Noltemeier (Universität Würzburg). It was a pleasure to note the international acclaim the seminar has found, the 37 participants came from 7 countries and 9 of them came from industry.

Lectures were given at the seminar, covering practically all important aspects of geometric modelling :

- solid modelling
- geometry processing
- feature modelling
- product modelling
- surfacepatches over arbitrary topologies
- blending methods in CAD
- scattered data algorithms
- multisurfaces
- smoothing and fairing algorithms
- NURBS

The discussion between industry and university has proven to be very fruitful. The scientists from industry were able to give many important and practible impulses for new research; in the opposite direction the university researchers have developed many new technologies, solving industrial problems, which may be transfered back to industry.
Everybody was impressed by the quality of the presentations; they acknowledged the importance of such research exchange between the various partners.

Participants

Robert E. Barnhill, Arizona State University
M. I. G. Bloor, Leeds University, UK
Pere Brunet, Univ. Catalonia, Barcelona
Wilhelm Brandenburg, Hella KG, Lippstadt
Georges-Pierre Bonneau, ENS Cachan (Paris)
Morten Daehlen, Center of Industrial Research, Oslo
Wendelin Degen, Universität Stuttgart
Matthias Eck, TH Darmstadt
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Tom Lyche, University of Oslo
Heinrich Müller, Universität Freiburg
Hartmut Noltemeier, Universität Würzburg
Bruce Piper, Rensselaer Polytechnic Institute
Helmut Pottmann, Universität Hamburg
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Joe Warren, Rice University, Houston, Tx
Peter Wassum, TH Darmstadt
Michael J. Wilson, Leeds University, UK
Franz-Erich Wolter, MIT Cambridge
Christian Zirkelbach, Universität Würzburg

Triangular B - splines

H.-P. Seidel
University of Waterloo, Canada

Polar forms simplify the construction of polynomial and piecewise polynomial surfaces and lead to new surface representations and algorithms.

In paticular, we will discuss a new multivariate B - spline scheme that was developed jointly with W. Dahmen and C. A. Micchelli. The scheme is based on the construction of a new spline space which is optained by matching B - patches with simplex splines, and allows to model piecewise polynomial surfaces with optimal smoothness over arbitrary triangulations of the parameter plane. Our results will be illustrated by examples from a first test-implementation of the new scheme that is currently under way at the University of Waterloo.

Geometry Processing

Robert Barnhill
Arizona State University, U.S.A.

Geometry Processing is the determination of geometric aspects of curves, surfaces and volumes. We discuss two principal topics in geometry processing: surface/surface intersections and offset surfaces. Our SSI algorithm draws on several years of experience and currently includes flatness criteria, edge linearity measures, adaptive marching, with modern computer science data management. We treat general parametric surfaces, both for SSI and for offsets. For our offset surface works we devise approximate offset surfaces of two types: rectangular, based on Farouki's ['86] publication in CAGD and triangular, based on extensions of Piper's ['87] publication in Farin's *Geometric Modelling*, SIAM.

We conclude with pointers to another topic, multidimensional interpolation, continued by Tom Foley. We use isophotes as an interrogation tool, a technique learned from earlier mettings here.

Hybrid Bezier Patches and Scattered Data Interpolation

Tom Foley
Arizona State University, U.S.A.

A hybrid cubic Bezier patch is introduced where the nine boundary control points on the triangle are fixed and the inner Bezier point is a rational quadratic function of three points, each tied to an edge of the triangular patch. This compact form allows one to use the deCasteljau algorithm for evaluation. With a minor modification the deCasteljau algorithm can yield directional derivatives and tangent plane. The side-vertex and BBG interpolants can be written in this compact (non-procedural) form. Because of the compact geometric form we present a method for selecting cross boundary derivatives that yields an interpolant to scattered data with cubic precision. Significant improvements are observed compared to using linearly varying cross boundary derivatives (which are commonly used). <joint work with Karsten Opitz >.

We also presented a transfinite method for selecting cross boundary derivatives based upon quadratic interpolants to neighboring network curves. <joint work with S. Dayanand and R. Santhanana >.

Another interpolation problem we adressed was time dependent data where a sequence of scattered data (bivariate) problems are given at discrete times. Instead of treating this as a trivariate problem, we treat time as a special variable and present two classes of solutions. <joint work with R. Barnhill and D. Lane >.

A Modeling Scheme for the Approximate Representation of Closed Surfaces

Pere Brunet

Polytechnical University of Catalonia, Barcelona

An approximate octree representation for closed surfaces is presented, namely Face Octrees. Face Octrees are based on a hierarchical representation of the subdivision of the space, until either hommogeneous or face nodes ar reached. Face nodes contain a connected, sufficiently planar part of the surface within a tolerance ϵ. The representation $FO_\epsilon(S)$ of a surface S depends on ϵ and can be refined, $\{S, FO_\epsilon(S)\} \rightarrow FO_{\epsilon'}(S)$, $\epsilon' < \epsilon$. The face octree $FO_\epsilon(S)$ of S defines a thick surface $TS(S)$, union of all bands defined by face nodes; a band in a face node spans ϵ to both sides of the plane π approximating S in the node. The region $TS(S)$ contains S, $S \subset TS(S)$. The face octree representation can be generated through a recursive algorithm based on a clipping of the surface patches and a planarity test. When used as an auxiliary model together with S, it can be used efficiently for a number of interrogations and geometric operations. Besides the algorithm for the generation of $FO_\epsilon(S)$, algorithms are proposed for point-solid classification, line and plane intersection tests, and interference detection. Space complexity of the proposed model is discussed, and some bounds are presented.

Interactive Design using the PDE Method

M. I. G. Bloor & M. J. Wilson

University of Leeds

The PDE method of a surface design generates a surface by regarding it as the solution of a situably chosen partial differential equation. 'Free-form surface' is a term used to describe a surface whose shape can in some way be manipulated by a designer. This seminar will describe how free-form surfaces may be generated by a PDE method. The ways in which the shape of such surfaces may be influenced and the degree of control that may be exercised will be illustrated using video sequences recorded from a session on a Silicon Graphics workstation.

Functionality in Geometric Design

M. I. G. Bloor & M. J. Wilson
University of Leeds

This seminar will illustrate how the shape of objects whose surfaces are described by PDE surfaces may be improved using optimisation techniques.

The surface shape of many objects is importent for how well they perform their intended function. For instance it would be useful if the shape of a ship's hull could be varied to reduce the hydrodynamic drag it experienced, within the limits set by constraints derived from other functional reqirements, e.g. stability. Now, given an initial design for an object's surface it may be necessary to alter that design so as to attain certain performence targets; but, if the number of variables parametrizing that shape is large, computationally an optimization of the object's shape may be no small task.

The PDE method views the generation of a surface patch as a boundary-value problem. Thus a PDE surface is described by data distributed along its boundary curves, which means that relatively complex surfaces can often be described in terms of a limited number of shape parameters. Hence the task of improving the shape to meet functional requirements may be computationally tractable.

Featuremodelling with an object-oriented approach

Wilhelm Brandenburg and Dr. Wördenweber
Hella KG Hueck & Co.

The notion of 'features' is an integral part of the design methodology for vehicle lights at Hella and the system implementation supporting it. Object-oriented mechanism are utilised to define part structure and behaviour models. The mechanism is part of an 'application specific modelling plattform' or 'framework', wich allows application software to interact with the CAD/CAM system on a high-level and to capture, evaluate and store the design intent.

The paper describes the modelling approach which lead to the use of features. It outlines the implementation of features in an existing CAD/CAM system using an object-oriented paradigm. The paper finally illustrates feature-based modelling techniques in industrial application and lists practial advantages.

High Order Continuous Polygonal Patches

John A. Gregory
Brunel University, U.K.

The talk describes joint work with JÖRG M.HAHN, VINCENT LAU and JIANWEI ZHOU. In the first part a polygonal patch method is described which can be used to fill a polygonal hole within a k'th order continuous rectangular patch complex. The patch requires C^k extensions of the rectangular patch complex defined in terms of the rectangular patch parametrizations. In the second part, the problem of filling the polygonal hole with rectangular patches is considered.

Automated Feature Recognition and its Role in Product Modelling

Michael J. Pratt

Cranfield Institute of Technology, England

The concept of form features as local geometric configurations on the surface of an object is reviewed. Their importance in computer aided design, computer aided manufacture and other automated engineering applications is then explained. The origin of feature-data in product models may be either through the use of a feature-based design interface or through automated feature recognition from pure geometric model. The former does not in itself provide for all engineering needs during the life-cycle of a product, since the designer's features are related to functionality, which is not true in general of features required for other applications downstream of design. Automated recognition will therefore always be a necessity in an integrated system for design, analysis, manufacturing, quality control etc. Methods for this purpose are reviewed, and it is pointed out that the recognition process can be simplified if the product model contains not only geometric information but also details of the designer's feature view of the product. The need for feature recognition techniques in validity checking throughout the design process is next discussed. The paper concludes with suggestions for further work in the development of a formal language for defining features, having use for both creation and recognition of features. This will permit an integrated system to be configured to meet the precise requirements and models of operation of diverse engineering organisations.

Properties of Local Coordinates Based on Dirichlet Tessellations

Bruce Piper

Rensselaer Polytechnical Institue

Local Coordinates based on Dirichlet Tessellations were introduced in Sibson, 1982, "A brief description of natural neighbour interpolation". In: D. V. Barnett, editor, Interpolating Multivariate Data. The local coordinates have several properties, that make them attractive for use in problems like scattered data interpolation. They are defined geometrically by taking the ratio of the area of certain subtiles to a larger tile and are continuously differentiable except at the data sites. In this talk, we will exhibit a geometric interpretation for the gradients of the subtile areas and use this formula to prove that the local coordinates have linear precision.

Base Points and Rational Bezier Surfaces

Joe Warren
Rice University

Given a rational surface

$$
\begin{aligned}
x &= X(s,t) \\
y &= Y(s,t) \\
z &= Z(s,t) \\
w &= W(s,t),
\end{aligned}
$$

a base point is a parameter value (a, b) such that $x(a,b) = y(a,b) = z(a,b) = w(a,b) = 0$. This talk discussed several applications of base point to topics in CAGD. There applications include multi-sided patches, incompatible edge twist surfaces, and higher dimensional generalizations of the Bernstein-Bezier method.

Curvature Approximation & Knot Removal for Scattered Data

Bernd Hamann
Arizona State University, Tempe, AZ, U.S.A

Given a 2D triangulation of some surface in E^3 a method is presented for approximating the principal curvatures for the points in the triangulation. The method is based on constructing a local (least squares) approximation to the triangulated surface. The technique can easily be extended to higher-dimensional surfaces.

Further, an iterative algorithm is discussed for removing points from a point set in E^3 constituting a 2D triangulation. Weights are associated with each triangle determining whether it is to be removed or not. The weight for a single triangle is based on the curvature approximations at its vertices.

Interpolation and Approximation with Exponential B-splines in Tension

Tom Lyche
University of Oslo

Splines in tension were introduced by Schweikert in 1966 as a means of eliminating wiggles in cubic spline interpolations. These splines have smoothness C^2 and have one shape parameter per polynomial (exponential) piece A B-spline basis for these functions was introduced by Koch and the author. In the talk we explored the use of this basis for interpolation of curves and surfaces.

Partitioning Large Scenes of Geometric Objects

Christian Zirkelbach

Universität Würzburg

We are faced with the problem of representing proximity information in large scenes of geometric objects. We present a data structure called "Monotonous Bisector* Tree" and analyze some structural properties showing, that a Monotonous Bisector* Tree is proper tool for supporting neighborhood quaries, even in general metric spaces.

Let S be a scene of konvex objects in $\mathbb{R}^d$. We show that a Monotonous Bisector* Tree can be generated in $0(nlogn)$ time using $0(n)$ space, which is optimal.

Conditions and constructions for geometry continuity of adjacent surface patches

Peter Wassum

Technische Hochschule Darmstadt, FB Mathematik

The geometrically continuous joint between adjacent patches is widely regarded as the appropriate way to fit together surface patches when building up the surface. Due to the representation of surface patches in affine coordinates, the geometric continuity constraints of arbitrary order are developed using a recurrence formula derived form the concept of reparametrization. The possibility of rescaling linked to surface patch representations in homogeneous coordinates has additionally to be taken into account when formulating continuity constraints of arbitrary order. Necessary and sufficient conditions for the geometrically continuous joint of integral or rational parametrized - Bezier patches are obtained.

Best approximations of curves with respect to the Hausdorff distance

Wendelin L. F. Degen

Universität Stuttgart

In order to measure the distance between two parametric curves $t \mapsto x(t) \in \mathbb{R}^2$, $t \in [a,b]$ and $s \mapsto y(s) \in \mathbb{R}^2$, $s \in [c,d]$ we require that there is a reparametrization $\sigma : [a,b] \to [c,d]$ (a diffeomorphism) and a distance function $\rho : [a,b] \to \mathbb{R}$, such that

(i) the approximant can be represented as $y(\sigma(t)) = x(t) + \rho(t)\vec{n}(t)$ where $\vec{n}(t)$ is the unit normal vector of x at $t \in [a,b]$

(ii) $Det(y'(\sigma(t)), \vec{n}(t)) \neq o$ for $t \in [a,b]$

Then the *normal distance* $d_N(x,y) := max_{t\in[a,b]}|\rho(t)| = |\rho|_\infty$ can be used as a distance between the two curves x and y. In the case of "same endpoints" $(x(a) = y(c), x(b) = y(d))$ it turns out, that this distance is exactly the Hausdorff distance.

Now we apply the non-linear approximation theory of Mainardus/Schwedt to determine the best approximation among a certain n-dim. differentialbe manifold M of Bezier curves $y \in M$. There must be proved

(1) The differentiability of the distance function ρ with respect to the n parameters of M

(2) The local Haar condition of the tangent manifold $T_y M$

(3) The global Haar condition for each pair $y, \tilde{y} \in M$

It is shown that all these conditions are satisfied for different settings:

(a) Cubic Bezier curves with equal endpoints and equal tangents as the given curve at the endpoints

(b) General Bezier curves of degree n with the same endpoints

Therefore the theory can be applied.

To calculate the best approximants explicitly, an algorithm was developed, which is based on the fact that the best approximant contains an alternant. It starts with a calculation of the n + 1 extremal points of ρ; then the n parameters of M are varied, and a quasi-Newton's method to solve the non-linear system $\rho_1 + \rho_2 = 0, \ldots, \rho_n + \rho_{n+1} = 0$ can be used.

Several examples are given.

Multiface - Working with large Surface Areas

Peter Schramm

Mercedes Benz, Sindelfingen

In current CAD-systems surface models are quite generally represented in terms of (trimmed) tensor product spline surfaces. Now, a multisurface is an assembly of several freeform surfaces with the capacity to describe the geometric shape of a complex part. In addition to the single surfaces it also contains topological information i.e. neighboring relations.

The talk summarizes the main features of a multisurface as well as describing how it can be generated automatically, starting from a given set of surfaces. Further, special functionality for multisurfaces employed in the CAD-system SYRKO is presented illuminating the advatages of having a surperimposed means of order. Special attention is given to the problem of filleting a surface model which contains various edges and corners.

Generalized Weighted Splines

Richard Franke

Naval Postgraduate School, Monterey, CA, U. S. A

The work of Madych & Nelson (approx. Th. and appl.) and Dyn (approx. Th. VI) has characterized scattered data interpolants using radial basis functions such as multiquadrics as having the minimum (pseudo) norm among all interpolants in a certain reproducing kernel Hilbert space. The inner product is defined as the integral of a weighted product of generalized Fourier transforms. The weight function is the reciprocal of the generalized Fourier transform of the basis function. This characterization holds for interpolants formed by linear combinations of translates of radial basis functions that are conditionally positive definite. Conditionally positive definite functions are characterized by having generalized Fourier tranforms that are positive on $\mathbb{R}^d\backslash\{0\}$ and satisfy certain other criteria.

This characterization of scatterd data interpolants applies to a number of known methods, such as thin plate splines and multiquadrics, but also raises the possibility of constructing new interpolation functions (generalized weighted splines) minimizing other weighted (pseudo) norms in the Fourier transform space. Corresponding to each positive weight function is a radial basis function method, or alternatively, corresponding to each radial basis function which is conditionally positive definite, there is a scattered data interpolation method. Some new generalized weighted spline methods are mentioned, and the results of applying them to some data were discussed.

Shape Information in Industry Specific Product Data Model

Dieter Roller

Hewlett Packard GmbH, Böblingen, BRD

In this presentation first some insight in the overall goal of the project is given. This is essentially the development of a CIM solution part folio for the European Automatic Industry. An architectural approach is describt which is based on industry specific enterprise-wide information models. The product data model as one of them is then presented. In particular the representation of shape information within the product data model is given in more datail. Eventually some gained experiences from this project are given.

Composition of Tensor Product Bezier Representations

Dieter Lasser

Universität Kaiserslautern, BRD

Trim curves of surfaces, trim surfaces of volumes, curve and surface modlelling according to the free form deformation idea of Bezier, segmentation, reparametrization, geometric continuity are applications of functional compositions. Composition of Bezier simplices has been described by DeRose. This talk gives composition theorems for ploynomial and rational tensor product Bezier representations. Bezier spline and B-spline representations are getting addressed, too. Statements are getting illustrated by examples and pictures.

Differential Geometric Methods in CAGD

Franz-Erich Wolter

MIT, Cambridge, U. S. A.

The first part of this talk reports an necessary and sufficient criteria for second (and higher) order contact between two surfaces. Those criteria employ few 1-dimensional contact - or curvature conditions (e. g. prescribing normal curvatures) to control all curvatures or more generally to control higher order contact between two surfaces. One of the theorems treats the case where the surfaces have contact along a curve. The other one treats the case where the surfaces have contact in a single point. The order two case of both theorems is joint work with Joe Pegna at RPI. It is shown how the point contact theorem can be applied to compute the curvatures for surfaces which are defined by a degenerate representation.

The second part of the talk reports on how methods from local and global differential geometry can be combined to develop efficient methods for distance computations i.e. e.g. to trace points nearest on a surface to points on a space curve. Those methods employ:

1) Tensorial differential equations for orthogonal projections (Joint work with Joe Pegna at RPI)
2) Approximation of the Inverse of the Normal Map
3) Elimination of search areas using Taylor estimates
4) Topological vector field index methods
5) Global differential geometric methods employing the Cut Locus

Finally a number of applications for distance computations is given. Those applications include e.g. medial curve and Cut Locus computations. It is indicated how the Cut Locus can be used as a tool for shape classification.

Algorithmic Blending

Hartmut Prautzsch

Universität Karlsruhe

A simple procedure was presented which produces a four-sided piecewise bicubic C^1 -patch with prescribed boundaries and crossboundary derivatives.

The method produces a C^1-surface even if the data given along the boundaries exhibits incompatible first order and second order mixed partial derivatives. The procedure is a subdivision method and only computes iteratively midpoints of controlpoints.

The surface produced can be used instead of Gregory's square.

Free-Form Curves Based on Normal Curves

Helmut Pottmann

Universität Hamburg, BRD

The talk describes joint work with Tony DeRose. Stone and DeRose recently presented an analysis of planar cubic Bezier curves for the presence of shape charateristics (loops, inflections,...). Now we use the classical notion of a normal curve to rederive these results in a more direct geometric way. This approach has the advantage that it extends to higher degree curves as well as to rationals.

Simplification of Piecewise Linear Curves

Morten Daehlen

Center for Industrial Research, Oslo

Given a piecewise linear curve P and a tolerance $\epsilon > 0$, we find a new curve Q, with as few linear segments as possible, but so that the Hausdorff distance between P and Q is less than ϵ. The main applications of the simplification algorithm are data reduction and scaling of paramtric curves for graphical display.

Reconstruction of C¹ closed surfaces from 2D cross-sectional data

Keith Unsworth

University of Dundee, Scottland

A method for reconstructing a closed C^1 surface from given cross-sectional data is described. Each set of cross-sectional data is interpolated using a parametric shape preserving curve interpolation scheme, and adjacent interpolating curves are blended using Hermite interpolation. The surface is closed by defining a crown point and a base point, each of which is then used in the generation of the crown and base surface section. Consideration is also given to branching, which is catered for by the inclusion of a saddle surface between the contours where branching occurs.

Fair Nurbs

Gerald Farin

Arizona State University, U.S.A

Operator time is becoming more expensive, whereas computer time is becoming cheaper. Therfore we propose to automate the process of curve design. While standard NURB (for non-uniform rational B-spline) design needs a control polygon, a set of weights and a knot sequence, our new method only needs the control polygon, thus freeing the designer from tedious specification of extraneous "shape parameters"

We also present a method to improve an existing B-spline curve by removing "noise" from the curve definition. This is done by degree reducing each cubic B-spline segment and then re-integrating it into the original curve definition.

Variational Design of smooth rational Bezier-Curves and -Surfaces

Hans Hagen
Universität Kaiserslautern, BRD
Georges-Pierre Bonneau
Ecole Normale Superieure Cachan, France

Curves and surfaces designed in a computer graphics environment have many applications, including the design of cars, airplanes, shipbodies and modelling robots. The generation of "technical smooth" curves and surfaces (which are appropriate for the NC-process) from a set of two- or three dimensional data points is a key problem in the field of geometric modelling. One of the most promising curve- and surface-modelling methods is the NURBS-technique (NURBS - non uniform rational B-splines). The fundamental idea of the rational Bezier- and B-spline algorithms is to evaluate and manipulate the curves and surfaces by a (small) number of control points and weights. The purpose of our contribution is to present an algorithm to assign to the weights appropriate values to achieve technical smooth curves and surfaces. The standard fairness criteria in engineering are to minimize certain strain energy integrals. We aproximate these integrals by quadrature formulas. A calculus of variation approach based upon these criterias with respect to the weights of the rational curves and surfaces leads to non-linear and linear systems of equations, which are solved by special routines. Several real world examples are presented to illustrate the concept.

Development towards Product Modelling

Joachim Rix
Fraunhofer Arbeitsgruppe für Graphische Datenverarbeitung, Darmstadt

A concept of a product model was presented. This is based on the parameters of product life cycle, application areas, properties and product presentation. The relation of these aspects points out the need for an integration of the different data models into one product model. The development of the CAD Reference Model (GI-FG.4.2.1) and the Standard for Exchange of Product Model Data (STEP) were descibed. The necessary work of integration of the given interdisciplinary activities in a new CAD environment architecture was shown.

Automatic fairing of point sets

Mathias Eck
Technische Hochschule Darmstadt, BRD

Given a set of N datapoints P_i $(i = 1, \ldots, N)$, we derive a method based on geometry of differences (Sauer '71) to smooth them. Therefore we use the discrete curvatures and

torsions in the points to define local and global fairness criteria. The proper fairing procedure, then works iteratively as the method of Sapidis & Frain '89. Their method smooths cubic B-Spline curves by knot removal & knot reinsertion.

C^1-Smoothing of Multipatch BEZIER Surfaces

Wolfgang Schwarz

EDS Deutschland GmbH Rüsselsheim

Handling and modelling multipatch tensor product BEZIER Surfaces often cause continuity problems. A method is described how to approximate a given surface in such a way that C^1-continuity at the crossing point of four surface patches can be obtained. The approximated surface uses still a BEZIER representation with the same orders as before.

The idea is to choose the four BEZIER control points associated with the mixed derivatives to build a fourside on a tangent hyperbolic paraboloid. This fourside and along with it the hyperbolic paraboloid can easily be obtained by approximation, minimizing the sum of the four distance squares.

A Voronoi Diagram Based Clustering Algorithm

Thomas Schreiber

Universität Kaiserslautern

This paper describes a solution to the following problem: given a set of weighted multidimensional data points, find the cluster center points, which minimize the sum of the squared distances between each data point and its nearest cluster point. Because this problem is np-complete, we search for a good local minimum and apply a k-means-type algorithm by using multidimensional Voronoi diagrams. The Voronoi diagrams are created by an adaptive insertion of new cluster points in those areas where the largest error occurs. At the same time this method produces a hierarchical Delaunay triangulation of the data points at different degrees of accuracy.

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