Recent Technical Report List
November 1988 - February 1989

New York University
Courant Institute of Mathematical Sciences
Computer Science Department

396 HIERARCHICAL CONTROL SYSTEM

D. Clark, February 1989; also RR 167

Servo loops are widely used in robot control programs. The Hierarchical Control System (HIC) is an operating system for managing a hierarchy of servo loops. HIC is in use at NYU in the controller for the Utah/MIT hand. Key features of HIC are a simple and efficient scheduler for servos and asynchronous events and a (nominally) non-blocking message passing structure, the periodic data buffer. This report describes HIC in detail with examples of its use.

399 OPTIMAL THREE FINGER GRASPS

J. Demmel, G. Lafferriere, February 1989; also RR 170

We address the problem of optimal force distribution among three point fingers holding a planar object. A new scheme is presented which reduces the nonlinear optimization problem to a generalized eigenvalue problem which is easily solved. This scheme generalizes and simplifies results of Ji and Roth. The generalizations include all possible geometric arrangements and extensions to three dimensions and to the case of variable coefficients of friction.

410 OPTIMAL PARALLEL ALGORITHMS FOR MATCHING PROBLEMS

Z. Kedem, G. Landau, K. Palem, November 1988

Computing *characteristics* of *lineage functions* of forests is a fundamental step in solving several problems such as term matching and 2-dimensional pattern matching. We design optimal speedup parallel algorithms for computing such characteristics on a CRCW PRAM. We use these algorithms to design optimal speedup parallel algorithms for solving the following classical problems: 1. anti-unification, 2. classes of unification, 3. term matching, and 4. 2-dimensional pattern matching. All of these problems have a rich history in that optimal sequential algorithms, as well as suboptimal parallel algorithms for solving them have been reported before. We also extend our algorithms to run on the weaker CREW PRAM with optimal speedup as well. This will involve a simple randomization scheme for simulating concurrent writes through a use of hashing.

411 COMBINATORIAL COMPLEXITY BOUNDS FOR ARRANGEMENTS OF CURVES AND SURFACES

K. Clarkson, H. Edelsbrunner, L. J. Guibas, M. Sharir, E. Welzl, November 1988; also RR 177

We present upper and lower bounds for extremal problems defined for arrangements of lines, circles, spheres and alike. For example, we prove that the maximum number of edges bounding m cells in an arrangement of n lines is $\theta(m^{\frac{2}{3}}n^{\frac{2}{3}}+n)$, and that it is $O(m^{\frac{2}{3}}n^{\frac{2}{3}}\beta(n)+n)$ for n unit circles, where $\beta(n)$ (and later $\beta(m,n)$) is a function that depends on the inverse of Ackermann's function and grows extremely slowly. If we replace unit-circles by circles of arbitrary radii the upper bound goes up to $O(m^{\frac{3}{5}}n^{\frac{4}{5}}\beta(n)+n)$. The same bounds (without the $\beta(n)$-terms hold for the maximum sum of degrees of m vertices. In the case of vertex degrees in arrangements of lines and of unit-circles our bounds match previous results, but our proofs are considerably simpler than the previous ones. The maximum sum of degrees of m vertices in an arrangement of n spheres in three dimensions is $O(m^{\frac{4}{7}}n^{\frac{9}{7}}\beta(m,n)+n^2)$, in general, and $O(m^{\frac{3}{4}}n^{\frac{3}{4}}\beta(m,n)+n)$ if no three spheres intersect in a common circle. The latter bound implies that the maximum number of unit-distances among m points in three dimensions is $O(m^{\frac{2}{3}}\beta(m))$ which improves the best previous upper bound on this problem. Applications of our results to other distance problems are given.

412 REVIEW OF MULTIFREQUENCY CHANNEL DECOMPOSITIONS OF IMAGES AND WAVELET MODELS

S. Mallat, November 1988; also RR 178

In this paper we review the recent multichannel models developed in psycho-physiology, computer vision and image processing. In psycho-physiology, multichannel models have been particularly successful for explaining some low-level processing in the visual cortex. The expansion of a function in several frequency channels provides a representation which is intermediate between a spatial and a Fourier representation. We describe the mathematical properties of such decompositions and introduce the wavelet transform. We review the classical multiresolution pyramidal transforms developed in computer vision and show how they relate to the decomposition of an image in a wavelet orthonormal basis. In the last section we discuss

the properties of the zero-crossings of multifrequency channels. Zero-crossings representations are particularly well adapted for pattern recognition in computer vision.

413 COMMON TANGENTS AND COMMON TRANSVERSALS

J. Goodman, M. Sharir, November 1988; also RR 179

The paper consists of two parts. The first part shows that, given a family of $k \leq d$ compact convex and separated sets in E^d (i.e. no $(k-2)$-flat intersects all these sets), the space of all oriented common tangent hyperplanes to these sets, which separate them in any fixed manner (i.e. contain some specified subset of them on their positive side and the rest on their negative side) is homeomorphic to the sphere S^{d-k}. The second part exploits this result to obtain sharp bounds on the combinatorial complexity of the space of all common transversal hyperplanes to a given d-separated family of n compact convex sets in E^d, showing this complexity to be $O(n^{d-1})$.

414 FUZZY DISK MODELING AND RENDERING OF TEXTURED COMPLEX 3D SURFACES OF REAL OBJECTS

X. Yang, November 1988; also RR 180

Three-dimensional geometric modeling in computer graphics is concerned with the representation, specification, and manipulation of free-form curves, surfaces, and volumes. This research explores a model for constructing representations of complex three-dimensional surfaces of real-world objects, such as sculptures in a museum, from sample points acquired with a special 3-D camera, and for synthesizing computer-generated pictures from this model. The difficulty of this problem comes from the complexity of the surface characteristics of such objects, which involve complicated irregular shapes and rich textures.

This thesis presents a new three-dimensional surface model — three-dimensional fuzzy disk model, for computer graphics display. This model allows any curved surface to be approximated b y a number of overlapping disks. A new blending method has been developed to generate smoothly curved surfaces from the overlapping disks. The shape of a blending surface can be controlled by varying some geometric parameters. This three-dimensional fuzzy disk representation is organized into a multi-resolution structure which allows adaptive refinement of surfaces details and supports a coarse-to-fine display process.

A scan-line rendering algorithm has been developed to synthesize images from the new model. We also present a simpler, less accurate, but more efficient approximation to the original model. In addition, we present a fast shadow penumbra approximation algorithm capable of generating soft shadows.

415 A DOUBLE EXPONENTIAL LOWER BOUND FOR DEGREE-COMPATIBLE GROBNER BASES

C. Yap, November 1988; also RR 181

We describe an ideal $J_{n,d}$ generated by $O(n)$ polynomials of degree $d+O(1)$ over $4n$ variables such that every Grobner basis for $J_{n,d}$ with respect to degree-compatible orderings has maximum degree $> +d^{2^{n-1}}$.

416 A NEW LOWER BOUND CONSTRUCTION FOR THE WORD PROBLEM FOR COMMUTATIVE THUE SYSTEMS

C. Yap, November 1988; also RR 182

We describe a commutative Thue system that has $2n$ variables and $O(n)$ rules, each rule of length $d+O(1)$ and that counts to d^{2^n} in a certain technical sense. This gives a more efficient alternative to a well-known construction of Mayr and Meyer. Such constructions are used to derive exponential space lower bounds for the word problem for commutative Thue systems, but more recently have been used to yield double-exponential degree bounds for Grobner bases and syzgies.

417 ON VERTICAL VISIBILITY IN ARRANGEMENTS OF SEGMENTS AND THE QUEUE SIZE IN THE BENTLEY-OTTMAN LINE SWEEPING ALGORITHM

J. Pach, M. Sharir, November 1988; also RR 183

Let $S = \{e_1, \ldots, e_n\}$ be a collection of n (intersecting) line segments in the plane. Suppose that all segments have their right endpoints lying on the same vertical line, and that we wish to bound the number of pairs of non-intersecting vertically visible segments that will intersect when extended to the right (e_i, e_j are *vertically visible* if there exists a vertical line segment connecting a point on e_i to a point on e_j and not meeting any other segment). We show that there are at most $O(n \log^2 n)$ such pairs, and only $O(n \log n)$ in the case of full rays, where the latter bound can be attained in the worst case. We apply these results to obtain similar upper and lower bounds on the maximum size of the queue in the original implementation of the Bentley-Ottman algorithm for reporting all intersections between the segments in S, i.e. the implementation where future events are not deleted from the queue. We also show that, without the extra conditions on the segments in S and on the pairs of segments to be counted, the number of non-intersecting vertically visible pairs of segments is $O(n^{\frac{4}{3}}(\log n)^{\frac{2}{3}})$, and can be $\Omega(n^{\frac{4}{3}})$ in the worst case.

418 THE COMPLEXITY OF MANY CELLS IN ARRANGEMENTS OF PLANES AND RELATED PROBLEMS

H. Edelsbrunner, L. Guibas, M. Sharir, December 1988; also RR 184

We consider several problems involving points and planes in three dimensions. Our results include: (i) The maximum number of faces bounding m distinct cells in an arrangement of n planes is $O(m^{\frac{2}{3}}n\log n + n^2)$; one can calculate m such cells, specified by a point in each, in worst-case time $O(m^{\frac{2}{3}}n\log^3 n + n^2\log n)$. (ii) The maximum number of incidences between m points and n planes is $O(m^{\frac{2}{3}}n\log n + n^2)$, provided these points are vertices of the arrangement of these planes, but this number is only $O(m^{\frac{3}{5}-\delta}n^{\frac{4}{5}+2\delta} + m + n\log m)$, for any $\delta > 0$, for any collection of points no three of which are collinear. (iii) For an arbitrary collection of m points, one can calculate the number of incidences between them and n planes by a randomized algorithm whose expected time complexity is $O((m^{\frac{3}{4}-\delta}n^{\frac{3}{4}+3\delta} + m)\log^2 n + n\log n\log m)$, for any $\delta > 0$. (iv) Given m points and n planes, one can find the plane lying immediately below each point in randomized expected time $O([m^{\frac{3}{4}-\delta}n^{\frac{3}{4}+3\delta} + m]\log^2 n + n\log n\log m)$, for any $\delta > 0$. (v) The maximum number of facets (i.e. $(d-1)$-dimensional faces) bounding m distinct cells in an arrangement of n hyperplanes in d dimensions, $d > 3$, is $O(m^{\frac{2}{3}}n^{\frac{d}{3}}\log n + n^{d-1})$. This is also an upper bound for the number of incidences between m points and n hyperplanes in d dimensions, provided the points are vertices of the arrangement of these hyperplanes. The combinatorial bounds in (i), (v) and the general bound in (ii) are almost tight in the worst case.

419 EFFICIENT MOTION PLANNING FOR AN L-SHAPED OBJECT

D. Halperin, M. Overmars, M. Sharir, December 1988; also RR 185

We present an algorithm that solves the following motion-planning problem. Given an L-shaped body L and a 2-dimensional region with n point obstacles, decide whether there is a continuous motion connecting two given positions and orientations of L during which L avoids collision with the obstacles. The algorithm requires $O(n^2\log^2 n)$ time and $O(n^2)$ storage. The algorithm is a variant of the cell-decomposition technique of the configuration space ([SS], [LS]) but it employs a new and efficient technique for obtaining a compact representation of the free space, which results in a saving of an order of magnitude. The approach used in our algorithm seems applicable to motion-planning of certain robotic arms whose spaces of free placements have a structure similar to that of the L-shaped body.

420 THE FURTHEST-SITE GEODESIC VORONOI DIAGRAM

B. Aronov, S. Fortune, G. Wilfong, December 1988; also RR 186

We present an $O((n+k)\log(n+k))$ time, $O(n+k)$ space algorithm for computing the furthest-site geodesic Voronoi diagram of k point sites within a simple n-sided polygon.

421 COMPUTING ACCURATE EIGENSYSTEMS OF SCALED DIAGONALLY DOMINANT MATRICES

J. Barlow, J. Demmel, December 1988

When computing eigenvalues of symmetric matrices and singular values of general matrices in finite precision arithmetic we in general only expect to compute them with an error bound proportional to the product of machine precision and the norm of the matrix. In particular, we do not expect to compute tiny eigenvalues and singular values to high relative accuracy. There are some important classes of matrices where we can do much better, including bidiagonal matrices, scaled diagonally dominant matrices, and scaled diagonally dominant definite pencils. These classes include many graded matrices, and all symmetric positive definite tridiagonal matrices. In particular, the singular values and eigenvalues are determined to high relative precision independent of their magnitudes, and there are algorithms to compute them this accurately. The eigenvectors are also determined more accurately than for general matrices, and may be computed more accurately as well. This work extends results of Kahan and Demmel for bidiagonal and tridiagonal matrices.

422 A NEWTON TYPE ALGORITHM FOR PLASTIC LIMIT ANALYSIS

V. Gaudrat, November 1988

We consider a model problem from collapse load analysis for plane strain. A discretized version of the kinematic variational principle is solved by means of a Newton-type minimization algorithm. The numerical solution, which represents a possible collapse mechanism, is computed for various shapes of the domain.

423 A MEANING REPRESENTATION FOR GENERIC SENTENCES

T. Strzalkowski, December 1988

The subject of this paper is an adequate meaning representation for a certain type of generic sentences in natural language. Specifically, the following problems are addressed. (1) What does it mean for a sentence to be generic and what sets it apart from other non-singular sentences, (2) what kind of representation do we need to capture the meaning of a generic sentence, together with its truth conditions and, possibly, some implications.

424 INDUCTIVE INFERENCE AND ENCODING

P. Caianiello, December 1988

In a very general setting we study the problem of learning as a process of construction of higher level symbols by means of two simple operations: string formation and set formation. We reduce it to an optimization problem by recognizing two different viewpoints: (1) When learning is achieved by an observer with absolutely no bias and the only goal of efficient memorization (2) When the observer is biased by the knowledge that the structures sought for are intended for communication and inferencing purposes. We briefly discuss possible applications and new considerations which the approach makes possible. Given the generality of our standpoint and the form of the results obtained, we suggest that our approach sheds light on the process of learning both at the "symbolic" and the "subsymbolic" level.

425 ON-LINE MOTION PLANNING: CASE OF A PLANAR ROD

J. Cox, C. Yap, December 1988; also RR 187

In this paper we develop an algorithm for planning the motion of a planar "rod" or "ladder" amidst an environment containing obstacles bounded by simple, closed polygons. The exact shape, number and location of the obstacles is assumed unknown to the planning algorithm, which can only obtain information about the obstacles by detecting points of contact with the obstacles. The ability to detect contact with obstacles is formalized by move primitives that we call *guarded moves*. We call ours the *online motion planning* problem as opposed to the usual *offline* version. This is a significant departure from the usual setting for motion planning problems, in which the algorithm is given an explicit description of the scene as part of its input. What we demonstrate is that the retraction method can be applied, although new issues arise that have no counterparts in the usual setting. We are able to obtain an algorithm with path complexity ($O(k) = O(n^2)$) guarded moves, where n is the number of obstacle walls, and k the number of pairs of obstacle walls and corners of distance less than or equal to the length of the ladder) that matches the known lower bound [Ork85]. This lower bound holds for both the online and offline (where the environment is explicitly given) versions of the problem. The computational complexity of the algorithm $O(k \log n)$ matches the best known algorithm [Sfs] for the offline version.

426 A NOTE ON THE PAPADIMITRIOU-SILVERBERG ALGORITHM FOR PLANNING OPTIMAL PIECEWISE-LINEAR MOTION OF A LADDER

M. Sharir, January 1989; also RR 188

We present an improvement, by nearly an order of magnitude, of a recent algorithm by Papadimitriou and Silverberg for optimal motion planning for a ladder. The improved algorithm runs in time $O(n^3\alpha(n)\log^2 n)$, where n is the number of obstacle edges and where $\alpha(n)$ is the extremely slowly growing inverse Ackermann function.

427 TWISTS, TURNS, CASCADES, DEQUE CONJECTURE, AND SCANNING THEOREM

R. Sundar, January 1989

Sleator and Tarjan devised a self-adjusting binary search tree, called *splay tree*, that is competitive with many of the balanced search tree schemes for maintaining a dictionary. They conjectured that the splay algorithm is optimal, in an asymptotic sense, among the class of self-adjusting search algorithms that use only rotations to reorganize the tree. Tarjan was able to prove a corollary of this conjecture, called *scanning theorem*, which states that splaying requires $O(n)$ time to access the nodes of an arbitrary n-node binary tree in symmetric order. Generalizing the scanning theorem, he conjectured that the cost of performing a sequence of m deque operations on an Arbitrary n-node binary tree using splaying is $O(m+n)$. He showed that the conjecture holds when the output operations are restricted to one end of the deque. Lucas proved that the cost of executing any sequence of deque output operations on an initial tree having a certain special shape using splaying is $O(n.\alpha(n))$, where $\alpha(n)$ is an inverse of the Ackerman function.

In this paper, we prove an $O((m+n).\alpha(m+n))$ bound for the complete set of deque operations performed on an arbitrary initial tree using splaying. We derive this result by analyzing sequences of various rotational operations on binary trees. Our study was motivated by a conjecture of Sleator that we refute. We also prove a generalized version of the scanning theorem.

428 A LOGIC-BASED APPROACH TO DISCOURSE ANALYSIS

T. Strzalkowski, February 1989

A first step toward automating the process of discourse understanding is to grasp the meaning contents of the discourse message, at least the literal meaning. Although every utterance may be assumed to contribute something to the discourse meaning as a whole, this latter can only rarely be regarded as a simple sum of meanings of component utterances. Utterances, or sentences, making up a discourse are usually involved in complicated mutual dependencies, that often go beyond the text itself. A careful study of these extra-sentential and inter-sentential dependencies in discourse is necessary before a more successful attempt to design an automated discourse understanding system can be undertaken. We outline a fragment of the system of semantic rules for computing coherent continuations at any point in discourse by uncovering various links existing between an utterance and its context. Next, we describe an extension of the method to handle changes in the level of reference in discourse. In order to accomplish this we develop a multi-level model for representing and manipulating various types of non-singular terms. We outline a possible application to processing expository texts found in college textbooks on science and engineering.

429 COMBINATORIAL AND ALGORITHMIC ANALYSIS OF SPACE DECOMPOSITION PROBLEMS

B. Aronov, February 1989; also RR 189

The first part of the thesis studies geodesic Voronoi diagrams. The closest-site (respectively, furthest-site) Voronoi diagram of a finite set of *sites* in Euclidean space is a classical geometric structure, which partitions the space into a set of *Voronoi cells* each associated with a site, so that any point in the cell of site s is closer to s (resp. further from s) than to any other site. The structure of such diagrams for point sites in the plane has been completely characterized and well-known efficient algorithms exist for computing them.

Voronoi diagrams have been generalized by replacing the Euclidean distance by a more general metric and/or relaxing the assumption that sites be single points. We consider the closest- and the furthest-site Voronoi diagrams for a set of k point sites in a simple n-gon, defined by the internal geodesic distance inside the polygon. We demonstrate that the planar map defined by either diagram is comprised of $O(n+k)$ features of bounded complexity each and describe nearly optimal algorithms for constructing the two Voronoi diagrams. Namely, the closest-site geodesic Voronoi diagram can be computed in time $O((n+k)\log(n+k)\log n)$, while $O((n+k)\log(n+k))$ time is sufficient for the furthest-site diagram.

The second part of the thesis analyzes the structure of an arrangement of flat triangles in 3-space. The combined combinatorial complexity of all non-convex cells (i.e., non-convex components of the complement of the union of the triangles), maximized over all arrangements of n triangles is shown to be roughly $O(n^{\frac{7}{3}})$, improving the best previously known upper bound of $O(n^{3-\frac{1}{49}})$ for a smaller quantity—the maximum combinatorial complexity of a *single cell*.

Our result has applications to algorithmic motion planning, stemming from the well-known technique that transforms a polyhedral body translating in a polyhedral environment into a collection of convex polygonal plates in three-dimensional space; the set of placements of the body reachable from a starting configuration along a collision-free path corresponds to a cell in the arrangement of these plates. Thus analyzing the maximum combinatorial complexity of a single cell and obtaining a comparably efficient algorithm for its calculation constitutes a satisfactory solution to the translational motion planning just mentioned.

To this end, we also consider the problem of computing a single cell or a subset of cells in a three-dimensional arrangement of triangles, providing a nearly worst-case optimal randomized algorithm for solving the former problem and a less efficient procedure for the latter. In addition, we examine a few special classes of arrangements for which better estimates on the maximum single-cell complexity can be deduced and where computing a cell or any collection of cells appears easier.

430 A SINGLE-PASS ALGORITHM FOR ELIMINATING CONSTRAINT CHECKS IN ADA PROGRAMS

H.L. Operowsky and E. Schonberg, December 1988

We show that a global optimizer is not required to reduce the overhead of constraint checking in Ada programs. We present a series of data-flow equations for available expressions and use them as the basis for a simple algorithm to eliminate redundant constraint checks. The algorithm is syntax-directed and is executed in a single pass over the source program's abstract syntax tree. No control flow analysis is required. Our algorithm also includes constant propagation using an extended framework and induction variable analysis. Because the algorithm operates on the abstract syntax tree, induction variable analysis is simplified. Although programs with **goto** statements are not considered, the **exit** statement is handled fully. We also examine the effects of shared variables and exception handling on removal of constraint checks.