An Updated Cross-Indexed Guide to the Ray-tracing Literature*

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I. Introduction

Last summer we published the first cross-indexed guide to the ray-tracing literature (reference **Sr91** in the last section of this paper). We noted at the time that research on ray-tracing for image synthesis had accelerated in recent years: areas under active study now included ray-tracing in data visualization, ray-tracing for radiosity and parallel ray-tracing, in addition to more familiar ones like fast subdivision traversal, stochastic sampling and efficient intersection culling. That first edition contained more than 400 references and spanned the period from 1968 to February, 1991.

For this edition, our database has been updated to include papers published through November, 1991. New entries include material from this year's SIGGRAPH, Eurographics, Graphics Interface (Canada) and Computer Graphics International conferences; IEEE's second visualization conference; the Eurographics Society's special rendering workshop; and a number of papers from English and foreign language journals. The total number of references is now more than 500. As in the first edition, all are cross-indexed by author and keywords.

The rest of the paper is organized as follows. Section II contains a glossary of the keywords used for indexing. Section III is an index to the database by keyword while Section IV is an index by author. Section V concludes with the actual references.

As before, we note that errors and omissions are hard to avoid in a work of this type. We apologize to any authors that have been overlooked and welcome corrections and new entries for a future edition. All update material should be sent to the author at Animation Research or to his Internet e-mail address: speer@cs.colorado.edu.

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II. Keyword Glossary

"**acoustics**" ray-tracing applied to the visualization of hearing or sound.

"**adaptive subdivision**" subdivision of part or all of the *object space* (the space in which scene objects reside) according to the location of objects, their size or other scene parameters. Contrast with **uniform subdivision**.

Also see: **bounding volumes**, **space subdivision**, **subdivision (image)**, **voxels**.

"**adaptive termination**" halting of recursive tracing when some parameter associated with a ray drops below a certain level. The product of the reflectivity coefficients of intersected surfaces is often used for this purpose.

"**albedo**" the reflectivity of a planet, satellite or asteroid.

"**animation**" a system or algorithm for the synthesis of multiple incrementally different images. Amortization of computational costs over many frames is often discussed as well.

Also see: **language**.

"**antialiasing**" a method or methods are given for overcoming problems inherent in the point-sampling nature of 'classic' ray-tracing (**Wh80** in the References section).

Also see: **filtering**, **reconstruction**.

"**approximate ray-tracing**" an algorithm that approximates the image that would be made by 'pure' or 'classic' ray-tracing (**Wh80** in the References section), usually to save time.

Also see: **refraction**.

"**array processor**" a **simd** multiprocessor system whose processing elements operate synchronously.

Also see: **connection machine**, **hardware**, **mimd**, **multiprocessor**, **parallel**, **pipeline**, **processor farm**, **simd**, **transputer**, **vector computer**.

"**beams**" refers to a generalized ray whose cross-section is something other than a point. Depending on the algorithm, the beam may be a cone or have a polygonal cross-section.

"**benchmarks**" shell scripts or code to make databases to test a raytracing algorithm or a specific computer, or the results of such tests.

Also see: **picture data**, **procedural objects**, **testbed**.

"**bibliography**" reference is or contains a substantial bibliography on ray-tracing.

Also see: **history**, **survey**.

"**bounding volumes**" a geometrically simple object (sphere, rectangular parallepiped, etc.) that encloses a more complex object or group of objects. Used for culling sets of objects from testing for intersection with a ray.

Also see: **space subdivision**, **voxels**.

"**bsp trees**" Binary Space-Partitioning trees, first used in flight-simulator applications, adopted later for use in automated space-subdivision algorithms. The partitioning planes may or may not be parallel to a global scene axis.

Also see: **data structures**, **hashing**, **hierarchies**, **k-d trees**, **octree**.

"**bump-mapping**" modification, often systematic, of the reflection vector from a surface, giving the impression of detailed geometry.

Also see: **normal perturbation**, **texture**.

"**caustic**" computation of a pattern formed by the reflection or refraction of light from another curved surface.

Also see: **light concentration**.

"**coherence**" a term first used in the context of projective hidden-surface algorithms, used here to denote consistency either in the paths of, or in the sets of objects intersected by a group of rays.

"**color**" especially concerned with the computation of the colors of an image.

"**computational complexity**" indicates that a reference contains at least some discussion of (and in some cases, deals extensively with) the theoretical complexity of ray-tracing.

"**cones**" indicates that logical cones are used in the algorithm, to classify objects into regions, for example, or for actual intersection tests.

"**connection machine**" a **simd** array processor with dynamic interconnectivity. Made by Thinking Machines Corp.

Also see: **array processor**, **hardware**, **hypercube**, **message passing**, **mimd**, **multiprocessor**, **occam**, **parallel**, **pipeline**, **processor farm**, **simd**, **transputer**.

"**cray**" a vector supercomputer, made by Cray Research Corp.

Also see: **connection machine**, **hardware**, **multiprocessor**, **parallel**, **pipeline**, **simd**, **vector computer**.

"**csg**" the reference discusses the rendering of objects modeled by *csg* methods (Constructive Solid Geometry, boolean combinations of primitive solids and/or half-spaces).

Also see: **intersections**, **modeling**, **set-membership classification**.

"**data structures**" indicates that a reference discusses or uses data structures particularly tailored to ray-tracing.

Also see: **bsp trees**, **hashing**, **hierarchies**, **k-d trees**, **octree**.

"**dda**" Digital Differential Analyzer, a line-path generator for a discretized space. Used in the image plane or object space.

Also see: **grid**, **uniform subdivision**.

"**depth of field**" simulation of the depth-of-field effect (variation in focus of objects at different distances from a camera with given lens and f-stop).

Also see: **focus**, **motion blur**, **stochastic ray tracing**.

"**directional**" indicates that a reference particularly deals with the directional component of rays.

"**directional intensity**" the intensity of a point on a surface, viewed from a given direction.

"**directional reflection**" describes how light coming from a given direction is reflected from a point on a surface.

"**distributed memory**" a multiprocessor system in which each processing element has direct access only to part of the total system memory.

"**distributed ray tracing**" denotes an implementation or algorithm that divides the total computational work into sub-tasks and assigns (distributes) these to multiple processors. Should not be confused with **stochastic ray tracing**.

Also see: **hypercube**, **load balancing**, **load metric**, **message passing**, **mimd**, **multiprocessor**, **parallel**, **processor farm**, **transputer**.

"**efficiency**" deals with the efficient use of one or more processors. In a multiprocessor context, the concern is usually the effective use of the available processors. Otherwise, the major concern is generally a fast means of determining which objects intersect a given ray.

Also see: **approximate ray-tracing**, **multiprocessor**.

"**fields**" indicates an algorithm that deals with fields of data values as opposed to more common geometric objects like polygons, patches, etc.

Also see: **visualization**.

"**filtering**" the computation of values from a set of samples by convolution with a *filter kernel*.

Also see: **antialiasing**, **reconstruction**.

"**flames**" contains some discussion of the rendering of flames.

"**focus**" discusses how to control the apparent focal point of an image.

Also see: **depth of field**, **motion blur**, **stochastic ray tracing**.

"**form factor**" refers to the use of ray-casting to compute radiosity *form factors* (the fraction of light leaving one surface that strikes another).

Also see: **heat transfer**, **radiosity**.

"**fractal**" rendering (tracing) of an object whose dimension is best described by a real number as opposed to an integer.

Also see: **modeling**, **surfaces**, **terrain**.

"**gloss**" the shine of a smooth but not perfectly mirror-like surface. Difficult to simulate with 'pure' ray-tracing (cf. **Wh80** in the References section).

Also see: **reflection**.

"**grid**" a grid-like logical structure either imposed on a scene or inherent in its definition.

Also see: **height fields**, **uniform subdivision**.

"**hardware**" deals with the implementation of a particular ray-tracing algorithm in hardware.

Also see: **array processor**, **connection machine**, **cray**, **hypercube**, **load balancing**, **load metric**, **message passing**, **mimd**, **multiprocessor**, **occam**, **parallel**, **pipeline**, **processor farm**, **simd**, **transputer**, **vector computer**, **vlsi**.

"**hashing**" hashing is used by the algorithm.

Also see: **bsp trees**, **data structures**, **hierarchies**, **k-d trees**, **octree**.

"**heat transfer**" indicates that a reference uses methods associated with the field of radiative heat transfer.

Also see: **form factor**, **radiosity**.

"**height fields**" a surface whose height is specified as a function of the other spatial parameters, i.e., $y = f(x, z)$, or otherwise specified.

Also see: **grid**, **modeling**, **parametric surfaces**, **patches**, **surfaces**.

"**hierarchies**" a logical arrangement of primitive entities in multilevel parent-child order. May be an implicit part of the objects in the scene or a structure built during rendering.

Also see: **bsp trees**, **data structures**, **k-d trees**, **octree**.

"**history**" deals with the history of ray-tracing.

Also see: **bibliography**, **survey**.

"**hypercube**" a multiprocessor system that positions and interconnects processors at every 'corner' of a k–dimensional cube.

Also see: **array processor**, **connection machine**, **hardware**, **load balancing**, **load metric**, **message passing**, **mimd**, **multiprocessor**, **occam**, **parallel**, **processor farm**, **simd**, **transputer**, **vlsi**.

"**illumination**" presents and/or implements a computational model of the interaction of light with a surface.

Also see: **caustics**, **directional intensity**, **directional reflection**, **gloss**, **light concentration**, **lighting model**, **radiosity**, **reflection**, **refraction**, **shading model**, **shadows**, **visibility**.

"**image-space bounding**" bounding the projection of an object in the image plane, to reduce the number of *primary rays* (rays traced from the viewpoint).

Also see: **subdivision (image)**.

"**interactivity**" 'standard' ray-tracing (**Wh80** in the References section) is modified to try to make images at higher speed (interactive rates).

Also see: **previewing**, **subdivision (image)**.

"**interpolation**" the colors at some points in an image are calculated by interpolating the colors found by ray-tracing other image points. The interpolated points may be within the same pixel.

"**intersection caching**" storing the intersection point of a ray and an object that spans several regions, to save computation if the ray enters those regions.

"**intersections**" particularly concerned with the correctness of ray-object intersections: do a ray and object really intersect or is it a false alarm caused by numerical imprecision?

Also see: **csg**, **modeling**, **parametric surfaces**, **patches**, **quadrics**, **set-membership classification**, **splines**, **superquadrics**, **surfaces**, **swept surfaces**, **surfaces of revolution**.

"**introduction**" the reference gives an overview or introduction to ray-tracing.

Also see: **bibliography**, **survey**.

"**k-d trees**" a $k-$dimensional tree structure in which the nodes at level q use values from the $((q \bmod k)+1)$'th dimension. May be used in *object space* or the image plane.

Also see: **bsp trees**, **data structures**, **hierarchies**, **octree**, **subdivision (image)**.

"**language**" the reference gives a language for defining a sequence of images.

Also see: **animation**.

"**light concentration**" discusses the concentration of light when reflected or refracted from a curved surface.

Also see: **caustics**.

"**lighting model**" presents and/or implements a computational model of the geometric or electromagnetic properties of light.

Also see: **illumination**, **light concentration**, **radiosity**.

"**line integral**" the accumulation of values along a line segment, often part of a ray from the viewpoint.

Also see: **visualization**.

"**lisp**" related to *lisp*, the LISt Processing language developed by John McCarthy.

"**load balancing**" adjusting the computational load of individual processors in a multiprocessor system.

Also see: **connection machine**, **hypercube**, **load metric**, **message passing**, **mimd**, **multiprocessor**, **occam**, **parallel**, **processor farm**, **transputer**.

"**load metric**" a method for measuring the computational load of an individual processor.

Also see: **connection machine**, **hypercube**, **load balancing**, **message passing**, **mimd**, **multiprocessor**, **occam**, **parallel**, **processor farm**, **transputer**.

"**message passing**" communication between individual processors of a multiprocessor system.

Also see: **connection machine**, **hardware**, **hypercube**, **load balancing**, **load metric**, **mimd**, **multiprocessor**, **occam**, **parallel**, **processor farm**, **transputer**.

"**mimd**" Multiple-Instruction, Multiple Data, the most general class of multiprocessor.

Also see: **connection machine**, **hardware**, **hypercube**, **load balancing**, **load metric**, **message passing**, **multiprocessor**, **occam**, **parallel**, **processor farm**, **simd**, **transputer**, **vlsi**.

"**modeling**" more than the usual discussion of geometric modeling is given, or ray-tracing is used as part of the modeling process.

Also see: **csg**, **fractal**, **intersections**, **parametric surfaces**, **patches**, **quadrics**, **set-membership classification**, **splines**, **superquadrics**, **surfaces**, **swept surfaces**, **surfaces of revolution**, **terrain**.

"**motion blur**" simulation of the photographic effect caused by the movement of an object while the camera shutter is open.

Also see: **depth of field**, **focus**, **stochastic ray tracing**.

"**multiprocessor**" a computer system whose processing elements operate independently and asynchronously.

Also see: **array processor**, **connection machine**, **cray**, **hardware**, **hypercube**, **load balancing**, **load metric**, **message passing**, **mimd**, **occam**, **parallel**, **pipeline**, **processor**

farm, **simd**, **transputer**, **vector computer**, **vlsi**.

normal perturbation modification, randomly or otherwise, of the normal to a surface, making the surface look 'bumpy', wrinkled or patterned.

Also see: **bump-mapping**, **texture**.

"**object-oriented**" a highly modular, strictly-interfaced form of the ray-tracing algorithm.

"**occam**" the "assembly language of the **transputer**", developed by INMOS Corporation.

Also see: **array processor**, **connection machine**, **hardware**, **hypercube**, **load balancing**, **load metric**, **message passing**, **mimd**, **multiprocessor**, **parallel**, **processor farm**, **simd**, **transputer**, **vlsi**.

"**octree**" a tree in which any non-leaf node has eight children. Often used to adaptively subdivide scenes.

Also see: **adaptive subdivision**, **bsp trees**, **data structures**, **grid**, **hierarchies**, **k-d trees**, **space subdivision**, **uniform subdivision**, **voxels**.

"**parallel**" refers to multiple processors working simultaneously; contrast *sequential*.

Also see: **array processor**, **connection machine**, **cray**, **hardware**, **hypercube**, **load balancing**, **load metric**, **message passing**, **mimd**, **multiprocessor**, **occam**, **pipeline**, **processor farm**, **simd**, **transputer**, **vector computer**, **vlsi**.

"**parametric surfaces**" usually indicates bi-variate, vector-valued functions that sweep out a surface in three dimensions as the surface parameters vary.

Also see: **modeling**, **patches**, **quadrics**, **splines**, **superquadrics**, **surfaces**, **swept surfaces**, **surfaces of revolution**.

"**particles**" concerned with the rendering of *particle systems* (point-like objects with time-varying behavior).

"**patches**" a *patch* is another name for a portion of a parametric surface, usually the part formed when the controlling parameters are varied between 0 and 1.

Also see: **modeling**, **parametric surfaces**, **quadrics**, **splines**, **superquadrics**, **surfaces**, **swept surfaces**, **surfaces of revolution**.

"**penumbra**" the reference discusses or gives an algorithm for computing 'soft shadows' (penumbra) as opposed to shadows with sharp boundaries, the kind generated by the classic ray-tracing algorithm (**Wh80** in the References section).

Also see: **shadow polygons**, **shadows**, **lighting model**, **radiosity**.

"**physics**" means that the reference deals with the visualization of some phenomenon from physics.

"**picture data**" the reference includes data on the time or space needed to compute images. May be useful in comparing the performance of different algorithms.

Also see: **benchmarks**, **picture data (estimates)**, **software engineering**, **testbed**.

"**picture data (estimates)**" the reference includes estimates of the time needed to compute particular images.

Also see: **benchmarks**, **picture data**, **testbed**.

"**pipeline**" a set of computational units that perform operations on data in a fixed sequence.

Also see: **array processor**, **connection machine**, **cray**, **hardware**, **mimd**, **multiprocessor**, **parallel**, **processor farm**, **vector computer**.

"**plants**" the use of ray-tracing to help model plant growth.

"**previewing**" tracing a scene at low-resolution or in some other way that allows a user to see it at near-interactive speeds.

Also see: **interactivity**, **subdivision (image)**.

"**procedural objects**" geometric objects defined and generated algorithmically; fractal terrain, e.g.

"**processor farm**" a multiprocessing arrangement in which processors run the same program on different data assigned to them by a controlling processor.

Also see: **array processor**, **hardware**, **hypercube**, **load balancing**, **load metric**, **message passing**, **mimd**, **multiprocessor**, **parallel**, **simd**, **transputer**.

"**quadrics**" geometric objects made of second-degree surfaces such as spheres, ellipsoids, etc.

Also see: **modeling**, **parametric surfaces**, **patches**, **splines**, **superquadrics**, **surfaces**, **swept surfaces**, **surfaces of revolution**.

"**radiosity**" the calculation of diffuse lighting by methods from the field of radiative heat transfer, involving the computation of *form factors* and the solving of a set of simultaneous equations.

Also see: **form factor**, **heat transfer**, **illumination**, **shading model**.

"**ray casting**" used to denote the 'non-recursive' form of ray-tracing in which no reflection or refraction rays are traced. (See **Wh80** in the References section for the recursive form.)

Also see: **visualization**.

"**ray transforming**" refers to the transformation of a ray into the definition or modeling space of an object to check for and/or compute ray-object intersections. Can increase image computation time compared to implementations that intersect objects directly in *object space*.

"**reconstruction**" most generally, the construction from a non-uniform set of image samples of a *bandlimited* surface that interpolates them.

Also see: **antialiasing**, **filtering**.

"**reflection**" references that deal in depth with some aspect of the reflection of light, giving, for example, methods for dealing with anisotropy or with arbitrary reflectance functions.

"**refraction**" references that particularly focus on the refraction of rays or beams, or that give approximate, sometimes fast methods for computing it.

Also see: **approximate ray tracing**, **transparency**.

"**rendering**" covers the rendering of special objects or phenomenon, or discusses ray-tracing in the context of rendering in general.

Also see: **bump-mapping**, **caustic**, **depth of field**, **flames**, **focus**, **fractal**, **height fields**, **motion blur**, **normal perturbation**, **radiosity**, **reflection**, **refraction**, **shadows**, **texture**, **transparency**.

"**root finding**" a method for finding the roots of equations is given or used.

Also see: **intersections**.

"**scanline**" a line of pixels equal in number to the horizontal resolution of the image.

"**scanline algorithm (comparison)**" the performance of ray-tracing on a given scene is compared with that of a *scanline-style rendering algorithm.*

"**set-membership classification**" the determination of whether a given point is in, out or on the border of another set of points. For ray-tracing, usually means determining whether a ray and an object defined by boolean operations intersect.

Also see: **csg**, **intersections**, **modeling**.

"**shading model**" a model of and/or algorithm for calculating the color of a point on a surface based on the orientation of the surface to the viewpoint and light(s) and the illumination of the point. In some cases (with point sets, e.g.), the local surface must first be calculated or inferred.

Also see: **color**, **gloss**, **illumination**, **lighting model**, **radiosity**, **reflection**, **refraction**, **shadows**.

"**shadow polygons**" the computation and insertion into a scene of dark-colored polygons to represent shadowed regions.

Also see: **penumbra**, **shadows**.

"**shadows**" the reference presents or surveys ray-tracing algorithms for the computation of shadows.

Also see: **illumination**, **penumbra**, **shadow polygons**.

"**simd**" Same-Instruction, Multiple-Data, denoting a computer with a single instruction stream that operates on multiple data elements.

Also see: **array processor**, **connection machine**, **cray**, **hardware**, **mimd**, **multiprocessor**, **parallel**, **pipeline**, **vector computer**.

"**software engineering**" discusses the large-scale production of ray-tracing related software in contrast to algorithms per se.

Also see: **testbed**.

"**source code**" the reference contains actual code or a pointer to same (an *ftp* site, for example).

"**space subdivision**" uniform or adaptive subdivision (or both) of the *object space* of a scene (the space in which scene objects reside).

Also see: **adaptive subdivision**, **bounding volumes**, **subdivision (image)**, **uniform subdivision**, **voxels**.

"**splines**" dealing with spline curves or surfaces. The splines may be Bezier-type, B-splines, beta-splines or some other type.

Also see: **intersections**, **modeling**, **parametric surfaces**, **patches**, **quadrics**, **superquadrics**, **surfaces**, **swept sur-**

faces, **surfaces of revolution**.

"**stochastic ray tracing**" unfortunately called "distributed ray tracing" in early literature, refers here to the stochastic sampling of one or more of the integrals that determine the attributes of light at a point in a scene.

Also see: **depth of field**, **focus**, **motion blur**.

"**subdivision (image)**" the projection of a scene onto the image plane is subdivided, for divide-and-conquer savings, to assign regions to slave processors or to determine regions that need not be traced.

Also see: **adaptive subdivision**, **image-space bounding**, **interactivity**, **previewing**, **space subdivision**, **uniform subdivision**.

"**superquadrics**" quadric surfaces with an accompanying exponent that can be used to pinch, round or square off portions of the surface.

Also see: **modeling**, **parametric surfaces**, **patches**, **quadrics**, **splines**, **surfaces**, **swept surfaces**, **surfaces of revolution**.

"**surfaces**" an algorithm for the tracing of a particular surface or class of surfaces is given.

Also see: **fractal**, **intersections**, **modeling**, **parametric surfaces**, **patches**, **quadrics**, **splines**, **superquadrics**, **swept surfaces**, **surfaces of revolution**.

"**surfaces of revolution**" deals with ray-tracing a surface formed by the rotation of a planar curve about an axis.

Also see: **intersections**, **modeling**, **parametric surfaces**, **patches**, **quadrics**, **splines**, **superquadrics**, **surfaces**, **swept surfaces**.

"**survey**" the references survey developments in ray-tracing.

Also see: **bibliography**, **history**, **introduction**.

"**swept surfaces**" an algorithm is given for ray-tracing the surface formed when a given shape is swept along a specific path.

Also see: **intersections**, **modeling**, **parametric surfaces**, **patches**, **quadrics**, **splines**, **superquadrics**, **surfaces**, **surfaces of revolution**.

"**terrain**" an algorithm for the ray-tracing of a synthetic terrain surface is given.

Also see: **fractal**, **modeling**, **surfaces**.

"**testbed**" the reference discusses the ’mixing and matching’ of ray-tracing algorithms in a single program.

Also see: **benchmarks**, **picture data**, **software engineering**.

"**texture**" discusses how to do texture mapping when ray-tracing or uses textures to direct the rendering (tracing) process.

Also see: **bump-mapping**, **normal perturbation**.

"**transparency**" deals at some length with the rendering of transparent objects or surfaces.

Also see: **refraction**, **rendering**.

"**transputer**" a VLSI single-chip microcomputer with processor, memory and communication channels for connection to other transputers.

Also see: **array processor**, **connection machine**, **hardware**, **hypercube**, **load balancing**, **load metric**, **message passing**, **mimd**, **multiprocessor**, **occam**, **parallel**, **processor farm**, **simd**, **vlsi**.

"**uniform subdivision**" regular subdivision of part or all of the *object space* (the space in which scene objects reside) without regard to object location or other parameters. Contrast with **adaptive subdivision**.

Also see: **space subdivision**, **subdivision (image)**, **voxels**.

"**vector computer**" a computer whose instruction operands can be vectors.

Also see: **array processor**, **connection machine**, **cray**, **hardware**, **hypercube**, **mimd**, **multiprocessor**, **occam**, **parallel**, **pipeline**, **processor farm**, **simd**, **transputer**, **vlsi**.

"**visualization**" the graphic representation and display of large amounts of output data from an experiment, simulation or sensing device (medical scanner, e.g.).

Also see: **line integral**, **ray casting**.

"**vlsi**" Very Large Scale Integration, a set of techniques for the design of integrated circuits containing millions of switching elements, or chips designed by such techniques.

Also see: **array processor**, **connection machine**, **cray**, **hardware**, **hypercube**, **mimd**, **multiprocessor**, **occam**, **parallel**, **pipeline**, **processor farm**, **simd**, **transputer**, **vector computer**.

"**voxels**" the 3D analog of *pixels*, usually axis-aligned, rectangular parallelepipeds. Voxels may be inherent in the database or can be created by *spatial subdivision*.

Also see: **adaptive subdivision**, **bounding volumes**, **octree**, **space subdivision**, **uniform subdivision**, **visualization**.

III. Keyword Index

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adaptive subdivision Gl84, Kp85, NeO86, AK87, BM87, FS88, Gl88, QH88, JW89, KB89, Qu89, Gg90, McB90, SF90a

adaptive termination Ky79, Fi82, Ha83, HG83, MT87, GH88, Wt89, AK90

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