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WORKSHOP ON
THE INTEGRATION OF FINITE ELEMENT MODELING
WITH
GEOMETRIC MODELING
12 MAY 1987

FINITE OCTREE MESHING THROUGH TOPOLOGICALLY DRIVEN GEOMETRIC OPERATORS

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OCTREE TECHNIQUE

HIERARCHIC STRUCTURE

- PROVIDES POWERFUL DATA STRUCTURE

SPATIALLY ADDRESSABLE

- REGULAR HEXAHEDRA (PARALLELEPIPED)

FINITE INFORMATION

- DISCRETE PORTION OF THE MODEL

FINITE OCTREE

FINITE OCTREE - OVERVIEW

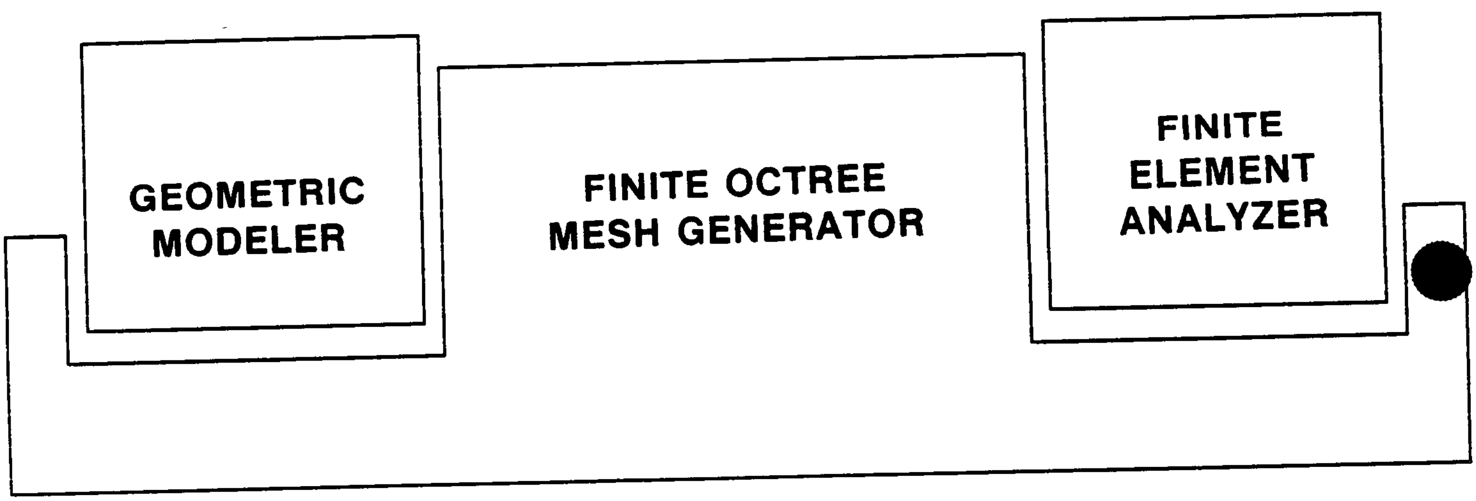
DISCRETIZATION OF SPACE

- EACH TERMINAL CELL (OCTANT) CONTAINS SPECIFIC DISCRETE MODEL INFORMATION.
- THE DISCRETE INFORMATION IS TOPOLOGICALLY CORRECT, BUT GEOMETRICALLY INCOMPLETE.
- EACH DISCRETE ENTITY CONTAINS POINTERS BACK TO THE MODEL, SO ALL GEOMETRIC AMBIQUITIES CAN BE RESOLVED.

THESE TERMINAL OCTANTS ARE FURTHER BROKEN UP INTO ELEMENTS.

THE ELEMENTS ARE THEN SUBMITTED TO AN ANALYSIS PACKAGE.

IF NEEDED, TERMINAL OCTANTS CAN BE EITHER RECOMBINED, OR FURTHER SUBDIVIDED IN AN ADAPTIVE TECHNIQUE.



FINITE ELEMENT SYSTEM

MODELER REQUIREMENTS

BOUNDARY REPRESENTATION -

- CONTAIN VERTEX, EDGE, FACE AND REGION ENTITIES ALONG WITH THE ADJACENCY INFORMATION.
- ALL COMPLETE AND UNIQUE GEOMETRIC REPRESENTATIONS CAN BE CONVERTED TO A B-REP.
- ANALYSIS ATTRIBUTES ARE DOMINATED BY INFORMATION ASSOCIATED WITH THE BOUNDARY.
- PROVIDES A GENERAL, ABSTRACT MEANS REPRESENTING NON-MANIFOLD STRUCTURE, ORIGINATING PERHAPS FROM AN IDEALIZATION OF THE MODEL

GEOMETRIC COMMUNICATION OPERATORS -

- RESTRICTED SET OF QUERIES ON BOTH THE TOPOLOGICAL ADJACENCY AS WELL AS THE UNDERLYING GEOMETRIC DEFINITION.
- SIMILAR IN APPROACH TO THE CAM-I APPLICATION INTERFACE SPECIFICATION (AIS).
- PROVIDES MEANS OF INTERFACING TO VARIETY OF MODELERS.

MODELER REQUIREMENTS

EACH TOPOLOGIC ENTITY HAS A CORRESPONDING GEOMETRIC ENTITY ASSOCIATED WITH IT.

- REGION TO VOLUME
- FACE TO SURFACE
- EDGE TO CURVE
- VERTEX TO POINT

VOLUME, FACE AND EDGE ENTITIES CAN BE PARAMETERIZED

IDENTIFICATION OF EACH ENTITY IS UNIQUE

OCTREE DISCRETIZATION

ONE COULD VIEW THE COMPLETE DISCRETIZATION OF A MODEL AS POINT (OCTANT CORNERS) AND CELL (BOUNDARY INTERSECTIONS WITH OCTANTS) CLASSIFICATIONS.

THIS CLASSIFICATION AND THE ASSOCIATION WITH THE OCTANTS WILL PROVIDE THE DATA FOR GENERATING THE FINAL MESH.

POINT AND CELL CLASSIFICATION TECHNIQUES ARE EXTREMELY GEOMETRY INTENSIVE AND MAY REQUIRE EXTENSIVE QUERIES.

THESE CAPABILITIES MUST BE CAREFULLY IMPLEMENTED FOR USE IN A GENERAL MODELING ENVIRONMENT.

FROM A MODELING STAND POINT:

- IN NON-IMPLICIT REPRESENTATIONS, POINT CLASSIFICATION (IN/OUT/ON TESTING) IS NOT EFFICIENT.

FROM A FINITE OCTREE PERSPECTIVE:

- CLASSIFICATION OF AN 'ON' POINT IS MOST IMPORTANT (DETERMINATION OF A BOUNDARY).

- RESOLVE COMPLICATIONS OF THE MODEL AS EARLY AS POSSIBLE, INCLUDING CONTRIBUTIONS FROM ANALYSIS ATTRIBUTES.

- RESOLUTION OF NON-MANIFOLD REPRESENTATIONS COULD BE VERY COSTLY (ex: hanging faces).

- ONCE A DISCRETE REPRESENTATION OF THE BOUNDARY OF THE MODEL IS COMPLETE, IT IS A TRIVIAL MATER TO IDENTIFY THE INTERIOR NODES.

OCTREE DISCRETIZATION

GENERAL METHOD

- INSERT TOPOLOGICAL ENTITIES OF THE MODEL FROM THE LOWEST ORDER UP
- VERTEX, EDGE, FACE, THEN INTERIOR (IF ANY)
- UTILIZE SPECIFIC GEOMETRIC COMMUNICATION OPERATORS, AVOID 'EX-PENSIVE' OPERATIONS

ASSOCIATE THE DISCRETE ENTITIES BACK TO THE MODEL AND THE MODEL TO THE DISCRETE ENTITIES.

- ALLOWS FOR RESOLUTION OF GEOMETRIC AMBIGUITIES
- ALLOWS FOR THE ASSIGNMENT OF GEOMETRICALLY ASSIGNED LOADS ON TO THE DISCRETE ENTITIES

GEOMETRIC COMMUNICATION OPERATORS

TWO TYPES CALLED BY THE FINITE OCTREE PROGRAM:

- 8 EXPECT INFORMATION ON TOPOLOGICAL ADJACENCY OR ATTRIBUTES APPLIED TO THE TOPOLOGY.
- 10 EXPECT SPATIAL DATA AS A RESULT OF A COMPUTATION USING THE UNDERLYING GEOMETRY OF THE MODEL.
- ALL ARE TYPICALLY AVAILABLE IN GEOMETRIC MODELERS.

GOES BEYOND THE STATIC FILE TRANSFER SCHEMES SUCH AS IGES, AND INTO A DYNAMIC INTERFACE WITH THE MODELER ITSELF.

GEOMETRIC COMMUNICATION OPERATORS RETURNING TOPOLOGICAL ASSOCIATIVITY

GET A LIST OF MODEL ENTITIES, SUCH AS VERTICES, EDGES, OR FACES FOR INSERTION INTO THE TREE.

GET THE MESH CONTROL ATTRIBUTE ON THE MODEL ENTITIES.

GET LOWER ORDER ENTITIES ASSOCIATED WITH A SPECIFIED ENTITY. (ex: vertices of on edge)

GET HIGHER ORDER ENTITY ASSOCIATED WITH A SPECIFIED ENTITY. (ex: regions on either side of a face)

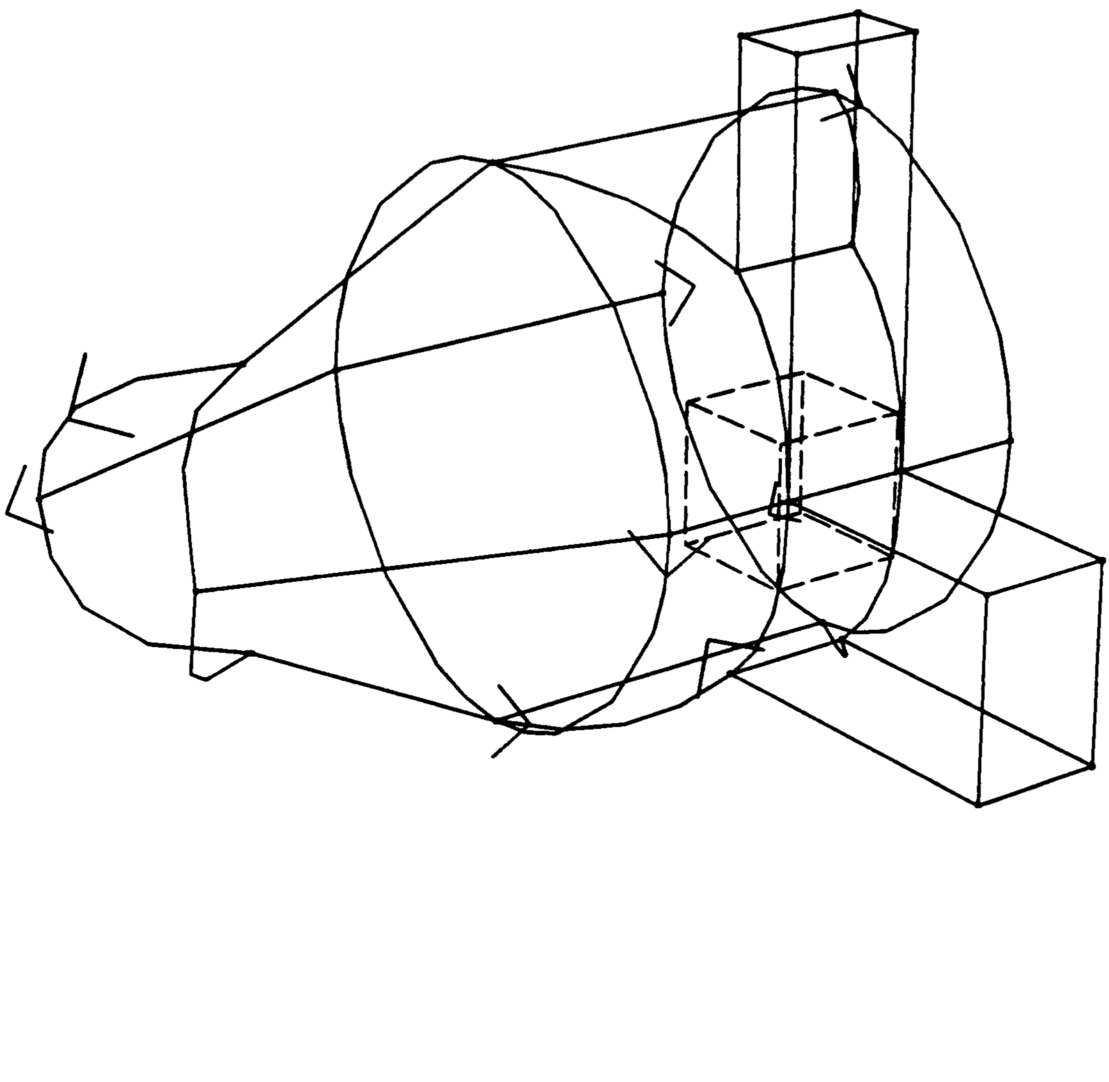
VERIFY WHETHER AN ENTITY IS ASSOCIATIED WITH ANOTHER. (ex: edge in face)

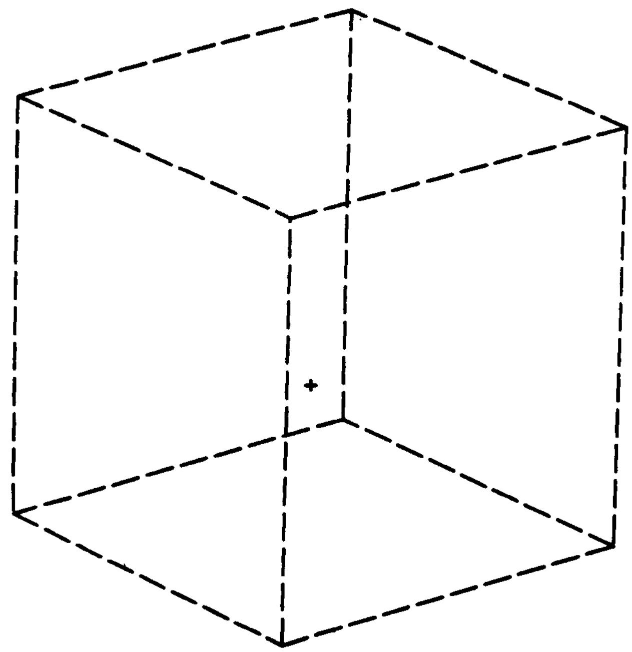
GEOMETRIC COMMUNICATION OPERATORS RETURNING SPATIAL DATA

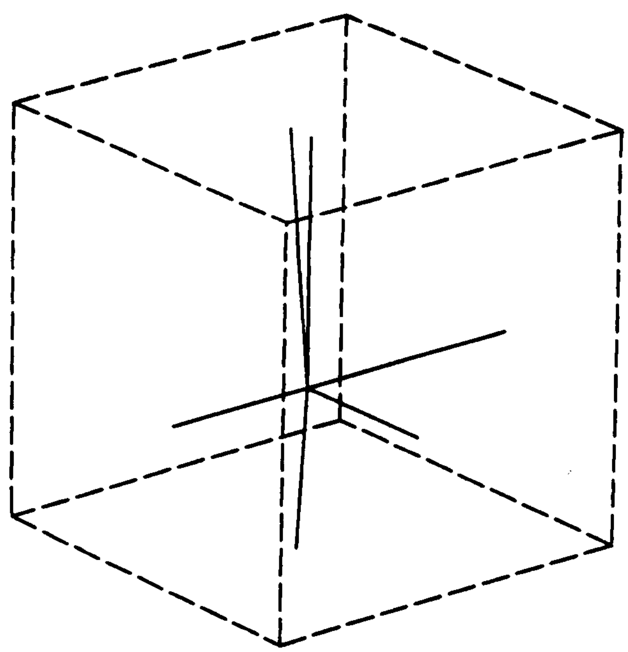
RETURNED DATA IS ALWAYS BASED ON POINT INFORMATION: COORDINATES, PARAMETER VALUES, NORMALS, DISTANCES.

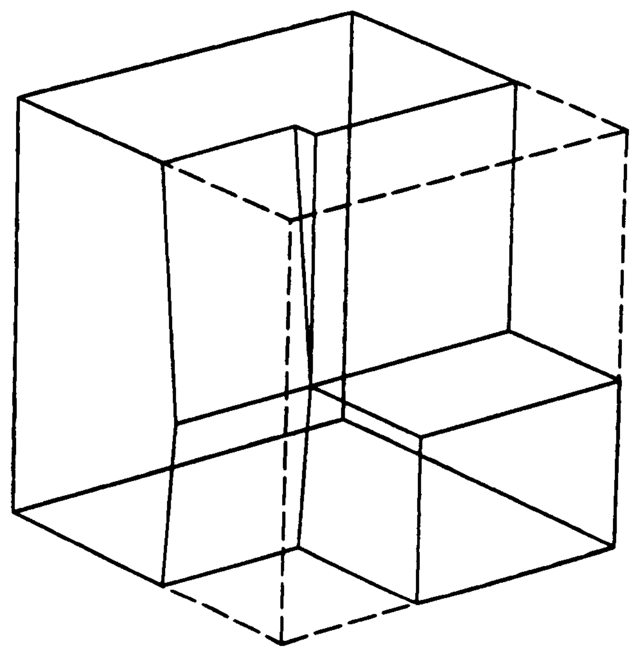
EXAMPLES:

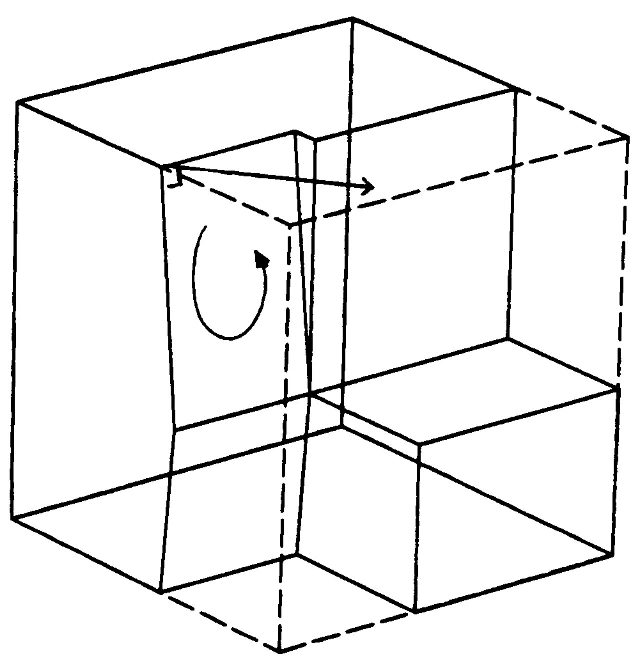
- GET_COORDINATE_OF_VERTEX
- INTERSECT_PLANE_WITH_EDGE
- INTERSECT_LINE_WITH_FACE
- GET_NORMAL_TO_FACE









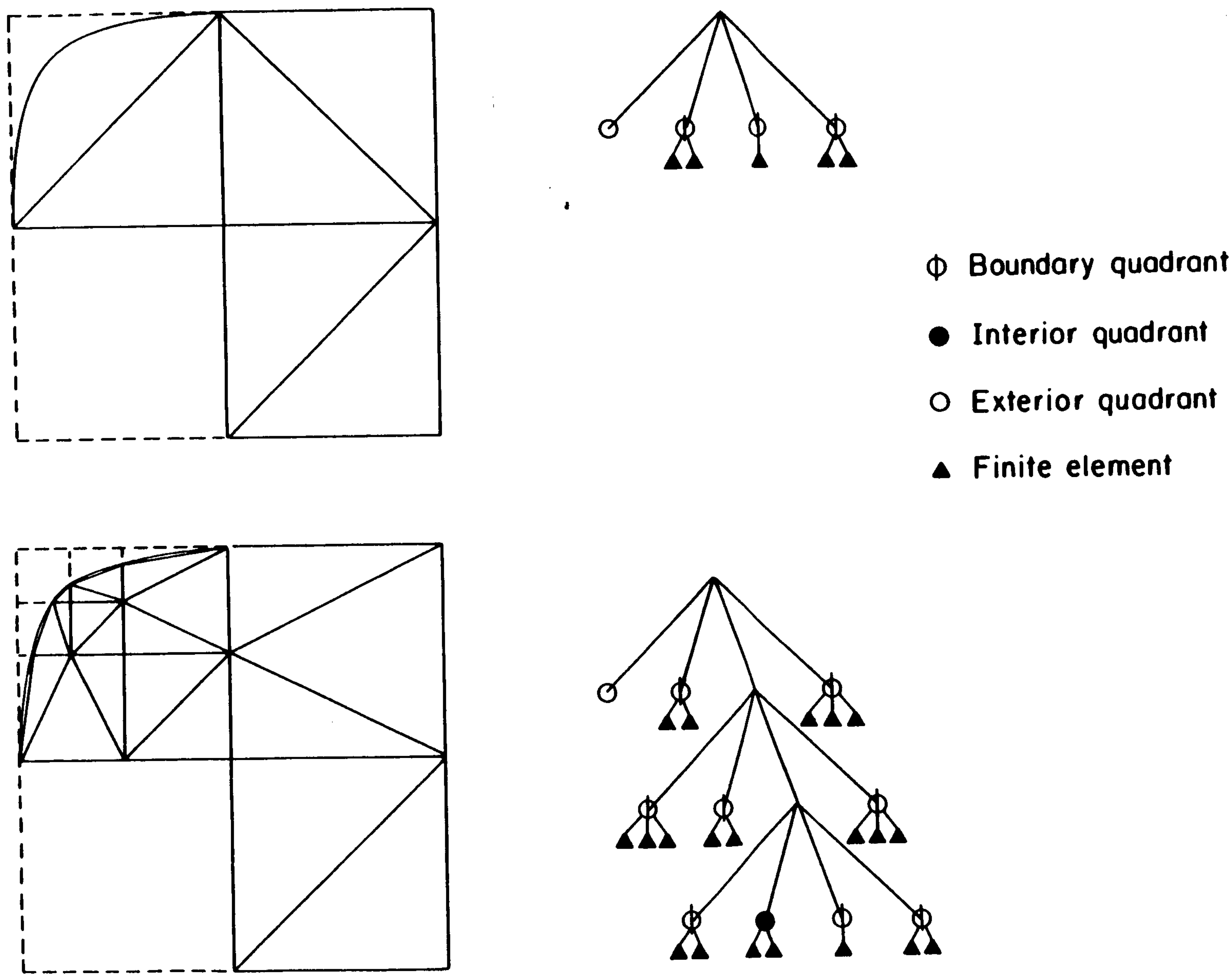


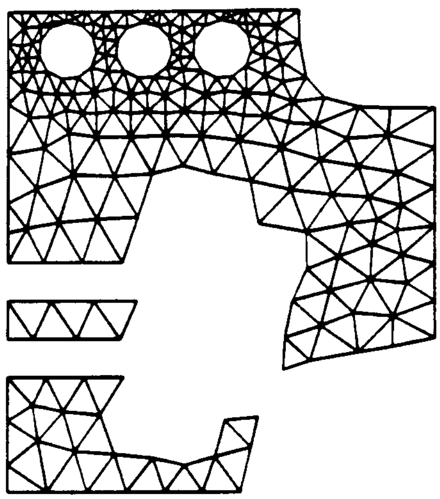
CAPABILITIES OF A FINITE OCTREE BASED MESHING PROCEDURE

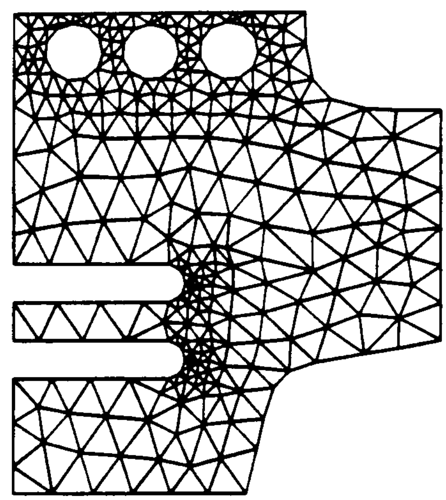
ADAPTIVE ANALYSIS TECHNIQUES WITH LOCAL REMESHING.

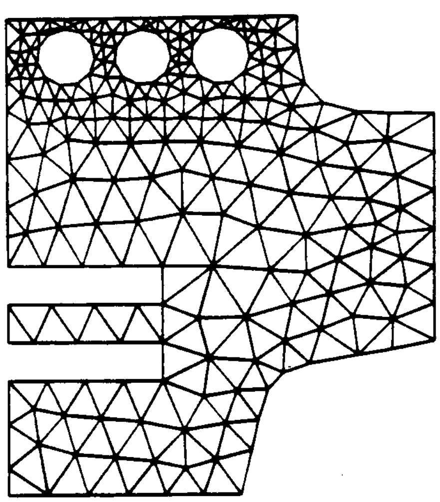
AUTOMATED METAL FORMING USING REMÉSHING CAPABILITIES.

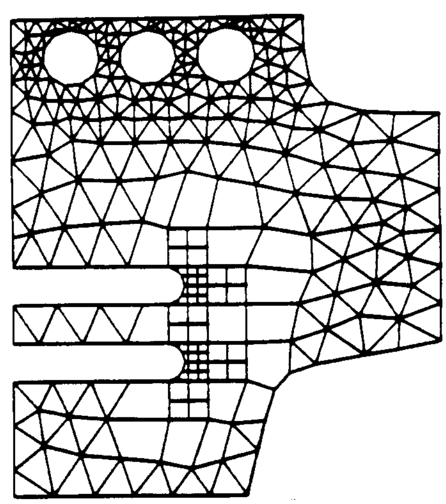
MODIFIED QUADTREE REFINEMENT

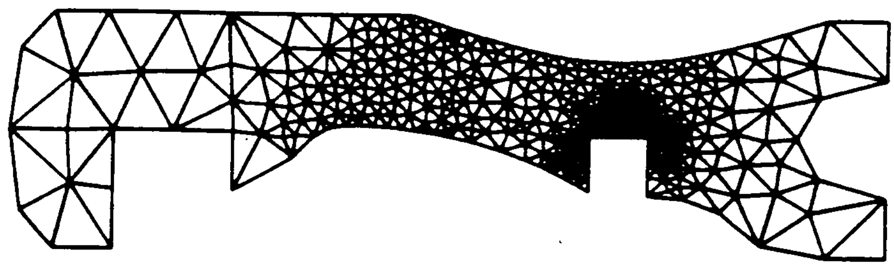


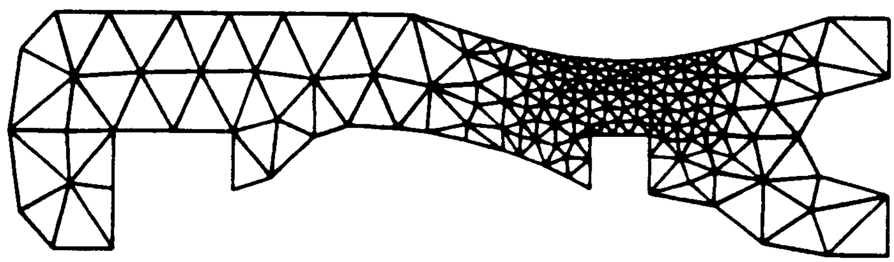


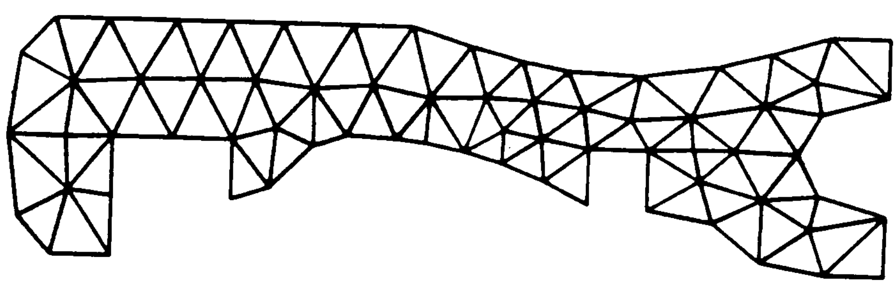


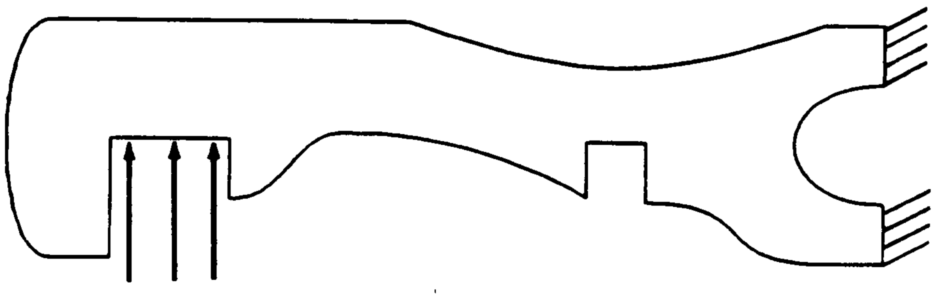


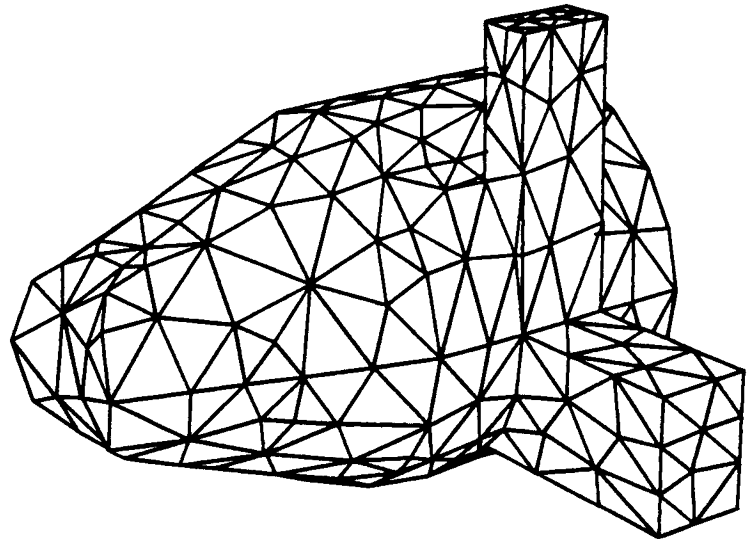


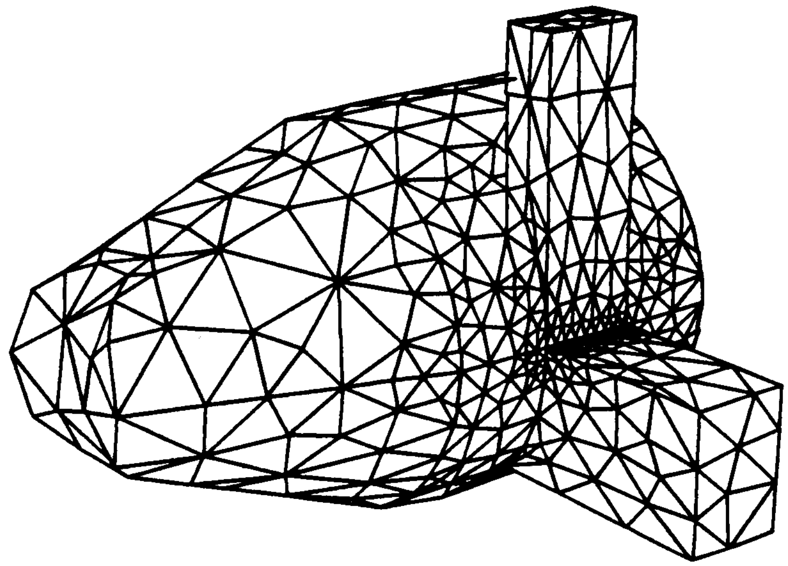


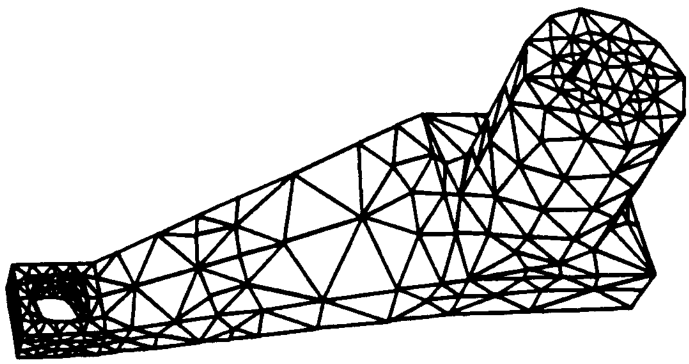


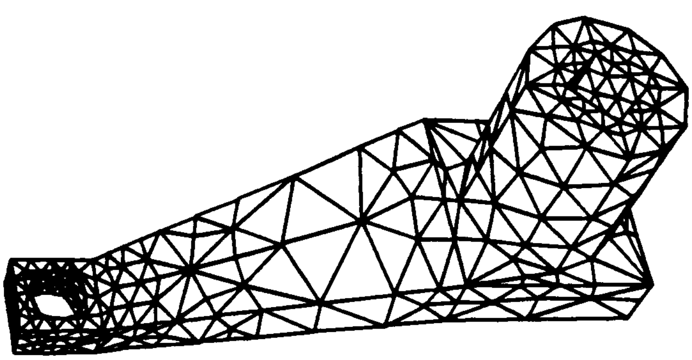


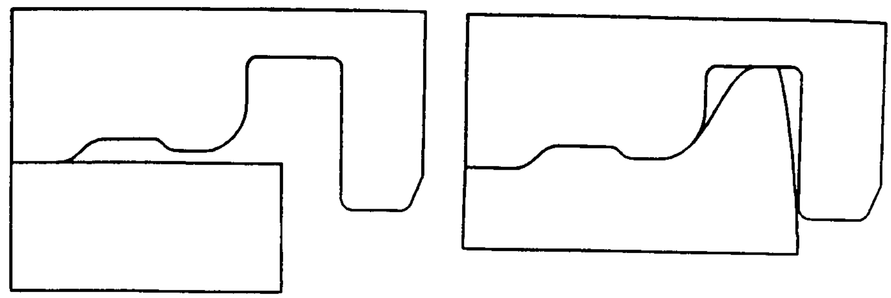




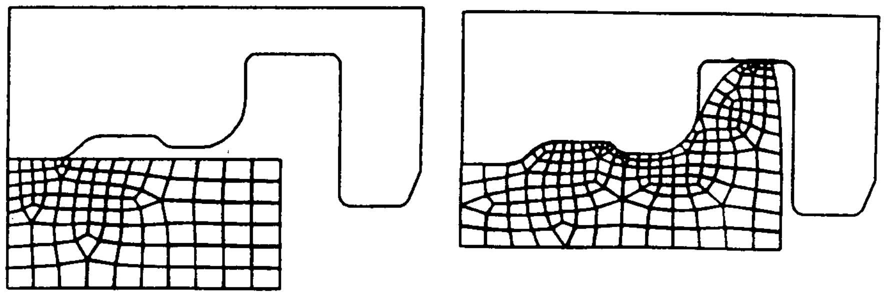








a) original geometry   b) geometry during forging



c) mesh for original geometry   d) mesh for current geometry

Figure 3. Modeling of forging process

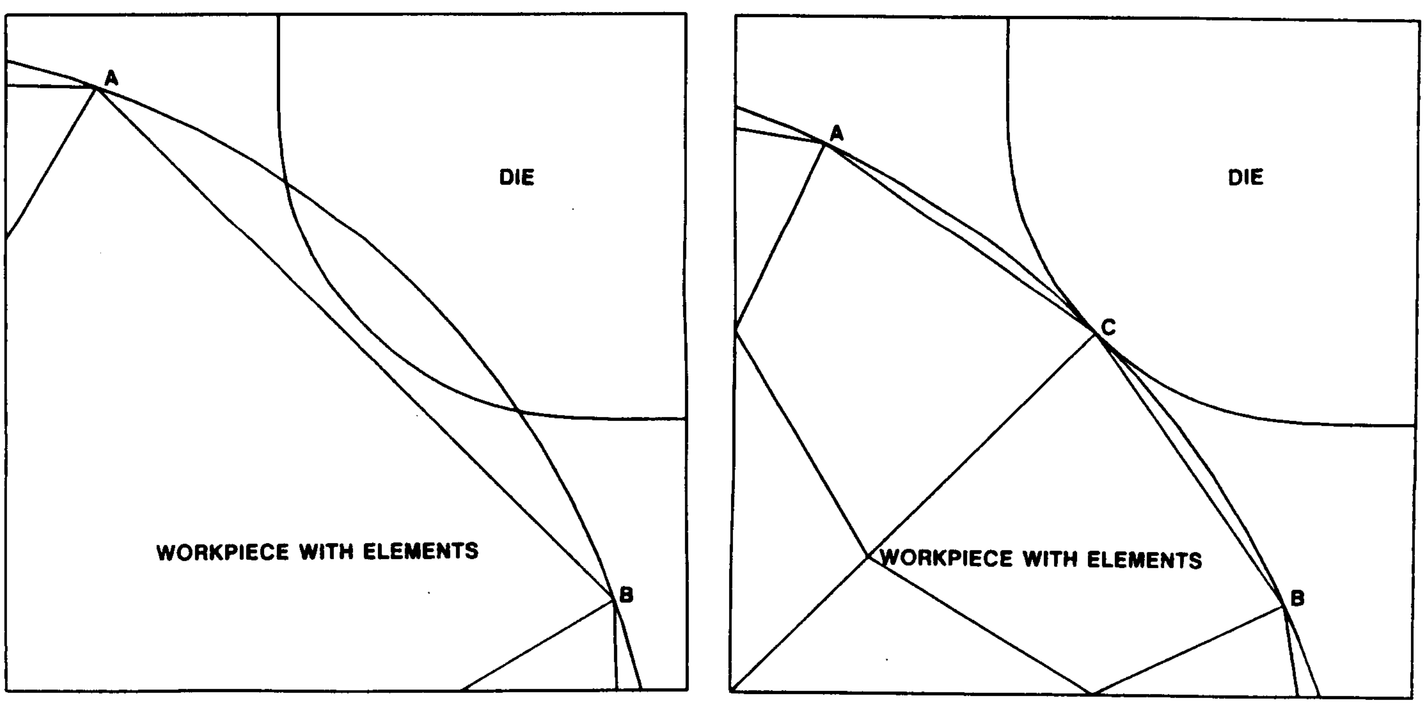


Figure 4. Volume control through geometric checks

SUMMARY

ADVANTAGES OF BOUNDARY REPRESENTATION

ADVANTAGES OF GEOMETRIC COMMUNICATION OPERATORS

IMPLEMENTATION PLAYS AN IMPORTANT ROLE IN THE INTEGRATION WITH A VARIETY OF GEOMETRIC MODELERS

CAPABILITIES OF CLOSED LOOP PROCESSES WITHIN A COMPLETE FINITE ELEMENT SYSTEM

ELEMENT GENERATION

PERFORMED ON AN OCTANT BY OCTANT BASIS

- EACH OCTANT REPRESENTS ONE OR MORE DISCRETE REGIONS OF THE MODEL, EACH DISCRETE REGION BOUNDED BY DISCRETE FACES
- TOPOLOGICALLY CORRECT, BUT GEOMETRICALLY INCOMPLETE
- GEOMETRIC COMMUNICATION OPERATORS ARE STILL NECESSARY

THE ELEMENTS ARE CREATED BY BREAKING THE DISCRETE REGION INTO A COLLECTION OF SIMPLEX ELEMENTS (TETRAHEDRONS)

CREATING THE ELEMENTS REQUIRES BOTH THE TRIANGULATION OF THE DISCRETE FACES AS WELL AS THE TETRAHEDRONIZATION OF THE DISCRETE REGIONS

ELEMENT GENERATION

FACE TRIANGULATION

- SINGLE LOOP OF CONNECTED POINTS IN 3-SPACE IS BROKEN INTO A SET OF SIMPLEX ENTITIES (TRIANGLES)
- CRITERIA FOR TRIANGULATION BASED ON VALIDITY AND QUALITY
- NEITHER OF THESE CRITERIA CAN BE RESOLVED BASED ON THE TOPOLOGY OF THE LOOP, THE GEOMETRY OF THE MODEL MUST BE QUERIED

REGION TETRAHEDRONIZATION

- BASED ON THE WORDENBER VOLUME TRIANGULATION TECHNIQUE
- OPERATIONS ARE EDGE REMOVAL AND VERTEX REMOVAL
- EACH REMOVAL MAY CREATE ADDITIONAL ENTITIES THAT MAY INTERFERE WITH THE GEOMETRIC MODEL, CAUSING INVALID ELEMENTS

IN SHORT, THE TOPOLOGY SUPPLIED BY THE DISCRETE REPRESENTATION, IS SIMPLY NOT SUFFICIENT FOR TETRAHEDRONIZATION, GEOMETRIC QUERIES ASSURE A CORRECT AND APPROPRIATE MESH