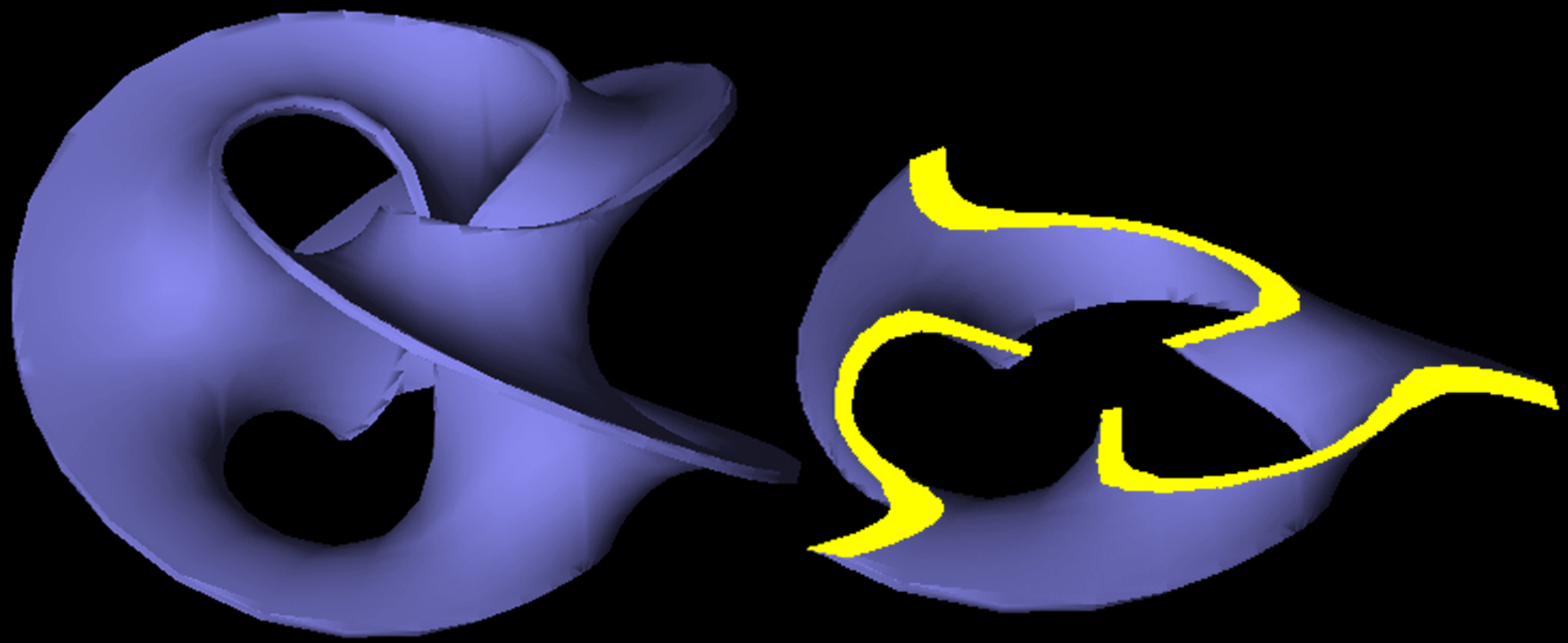
Layered Manufacturing

Sara McMains

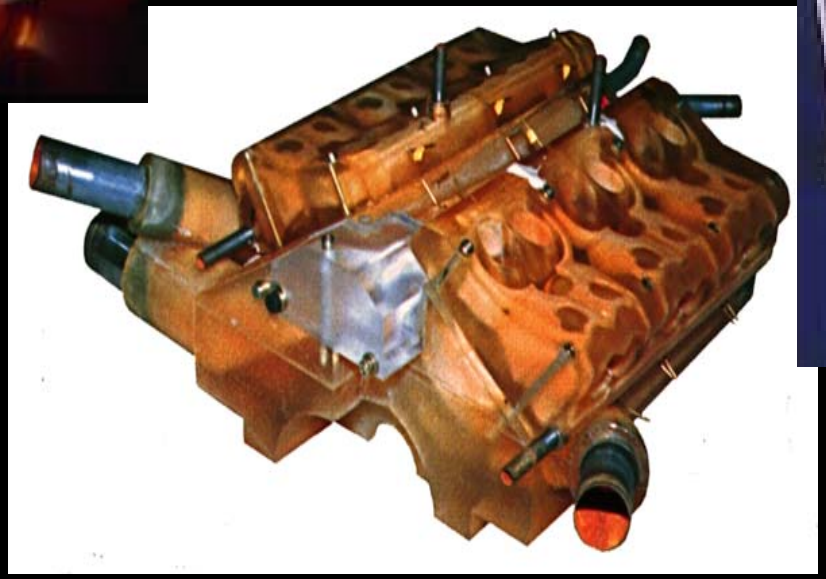
Layered Manufacturing (LM)
a.k.a. Solid Freeform Fabrication (SFF)
a.k.a. Rapid Prototyping (RP)

- Automated build of complex 3D shapes from 2.5-D layers



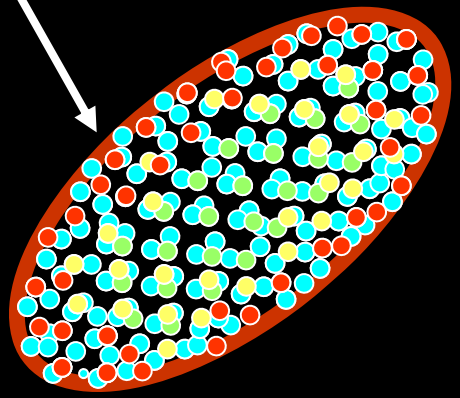
Industrial Applications of LM

- Design review
- Positives for molds
- Functional testing

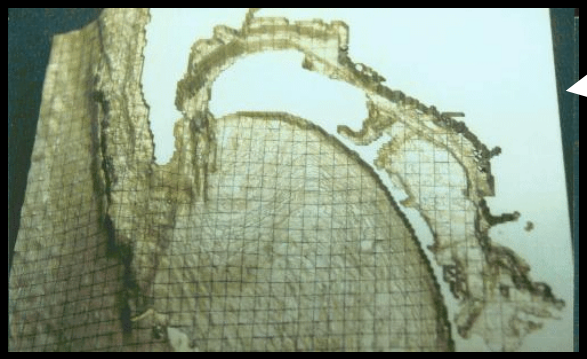


Medical Applications of LM

- Prosthetics
- Pharmaceuticals
  - Micro-structure control
- Tissue engineering

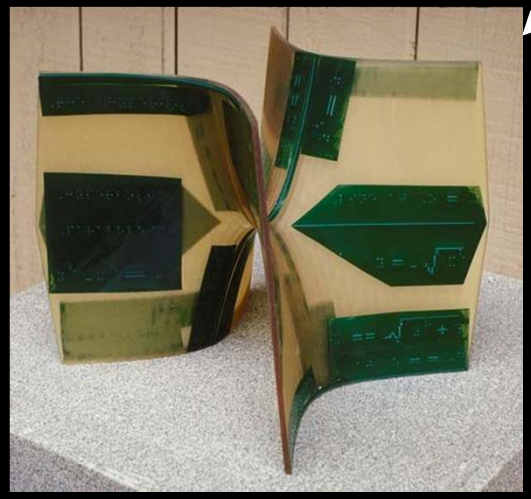


Educational Applications of LM

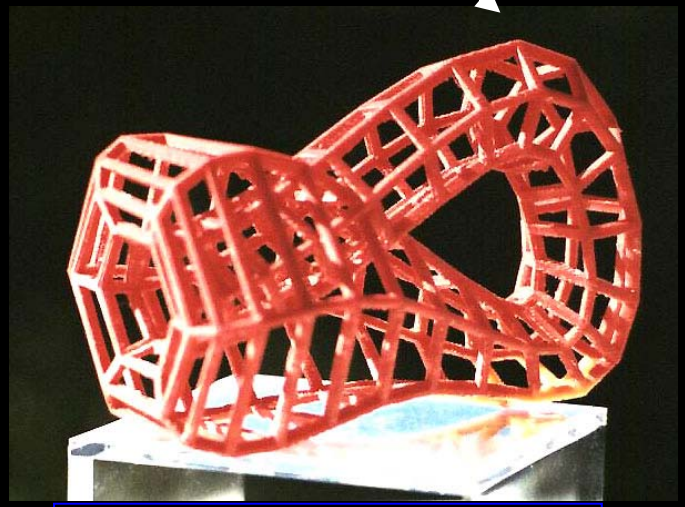


San Diego Harbor
(Mike Bailey)

- Scientific Visualization
- Topological Models
- Tactile Mathematics



Hyperbolic parabaloid w/ Braille annotations (Stewart Dickson)

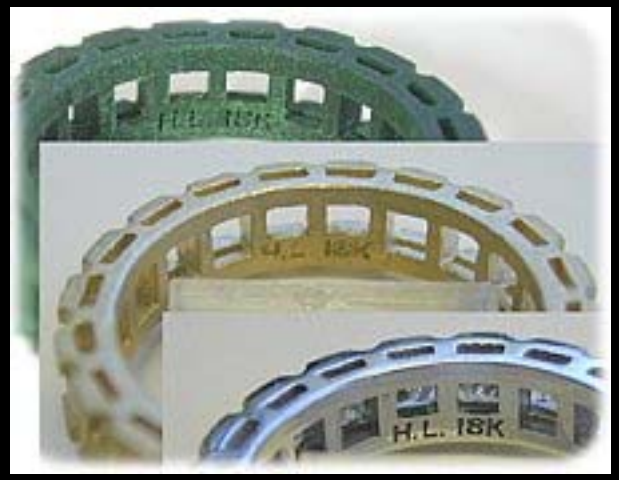


Klein Bottle Skeleton
(Carlo Séquin)

Artistic Applications of LM

– Jewelry
– Sculpture

"Ora Squared"
(Bathsheba Grossman)



LM vs. Conventional Manufacturing

- Subtractive
- Net shape
- Additive

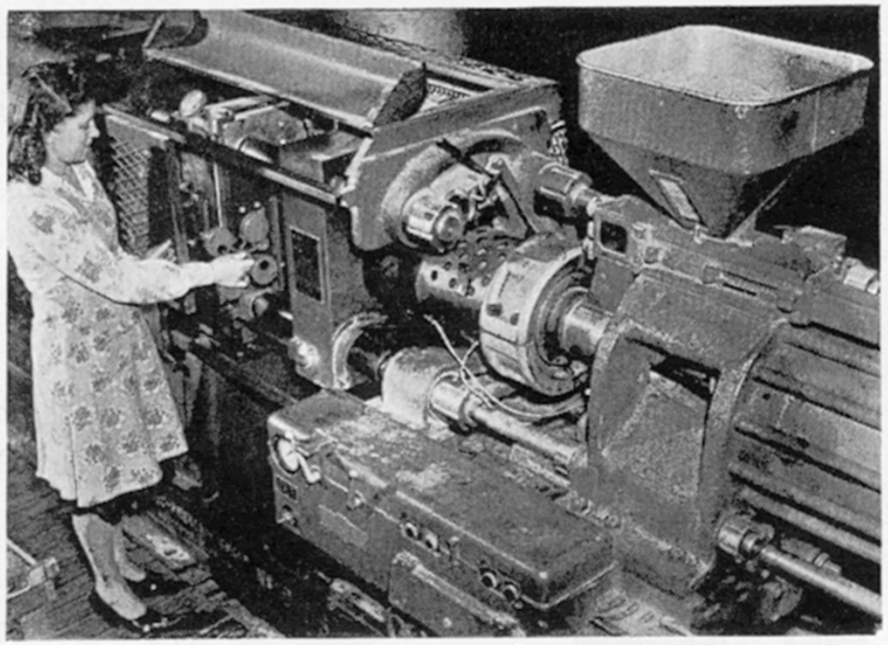
Conventional Manufacturing

- Subtractive
  - Start with simple stock
  - Remove unwanted volume
  - E.g.
    - Machining

Delcam

Conventional Manufacturing

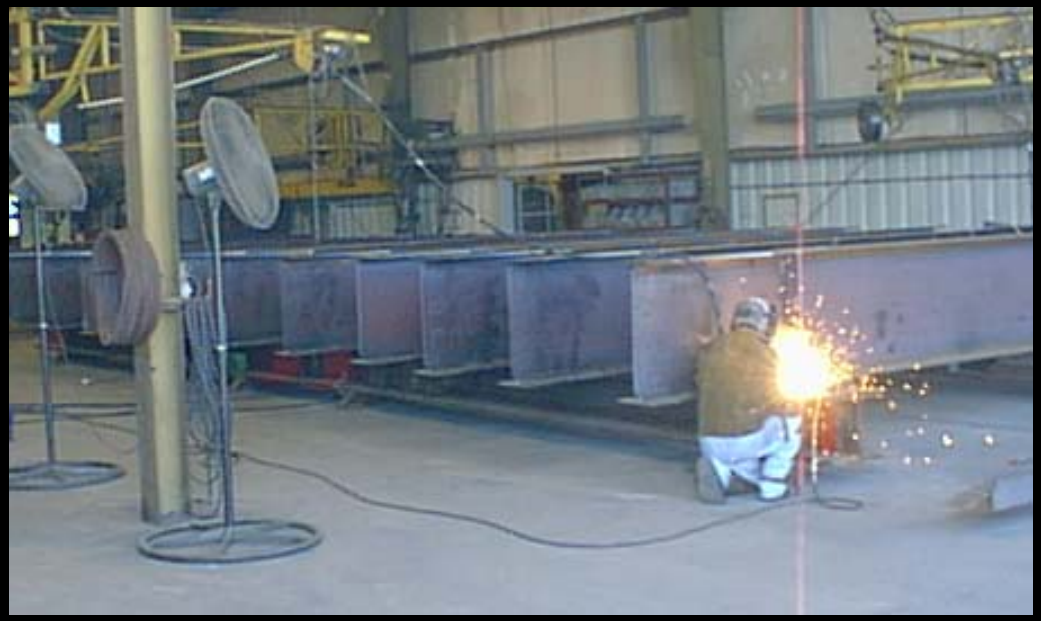
- Net shape
  - Start with simple stock
  - Reshape in die or mold
  - E.g.
    - Forging
    - Molding
    - Casting



(Courtesy Hercules Powder Co., Wilmington, Del.)

Conventional Manufacturing

- Additive
  - Combine complex sub-units
  - E.g.
    - Welding



Conventional Manufacturing

- Appropriate for production runs
  - Incremental costs low
- Not appropriate for small batch sizes or prototyping
  - Complex process planning
  - Special purpose tooling
  - Set-up costs high
  - Long lead times

Layered Manufacturing Characteristics

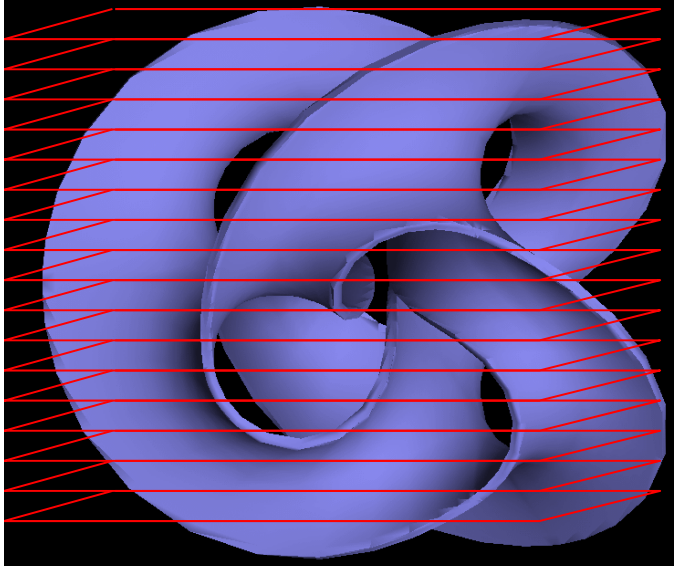
- Automated process planning based on CAD model
  - Short lead times
- No special purpose tooling
- Highly complex parts economical at low production numbers
- Perfect for prototyping

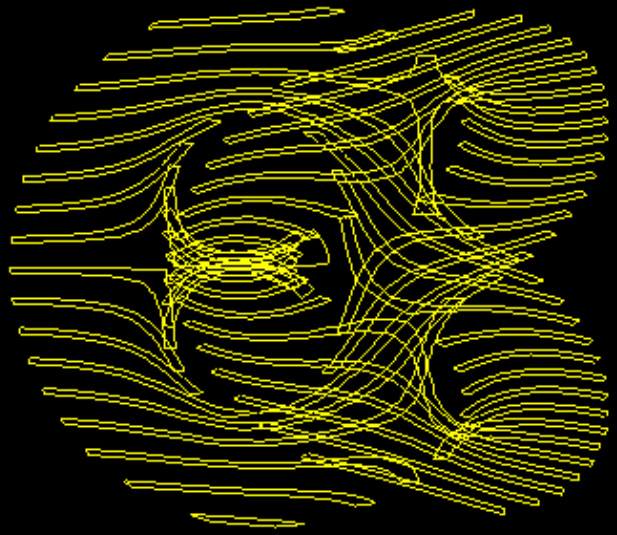
Benefits of Layers

- Layering manufacturing eliminates constraints
  - Tool clearance constraints
  - Mold releasability constraints
  - Fixture planning constraints

Layers

- 2.5-D slices through model
  - Slice interior is part geometry
  - Slice exterior may function as:
    - Fixture
    - Support





Support Handling (a)

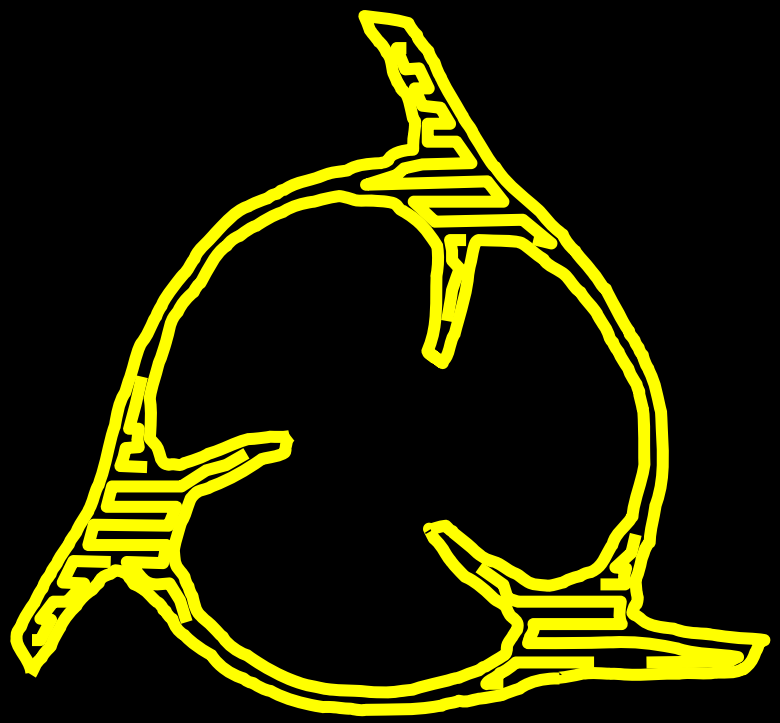
- Supports with planned geometry
  - Identify overhanging features
  - Selectively build supports beneath
  - Usually same material as part
    - Less dense for ease of removal

Support Handling (b)

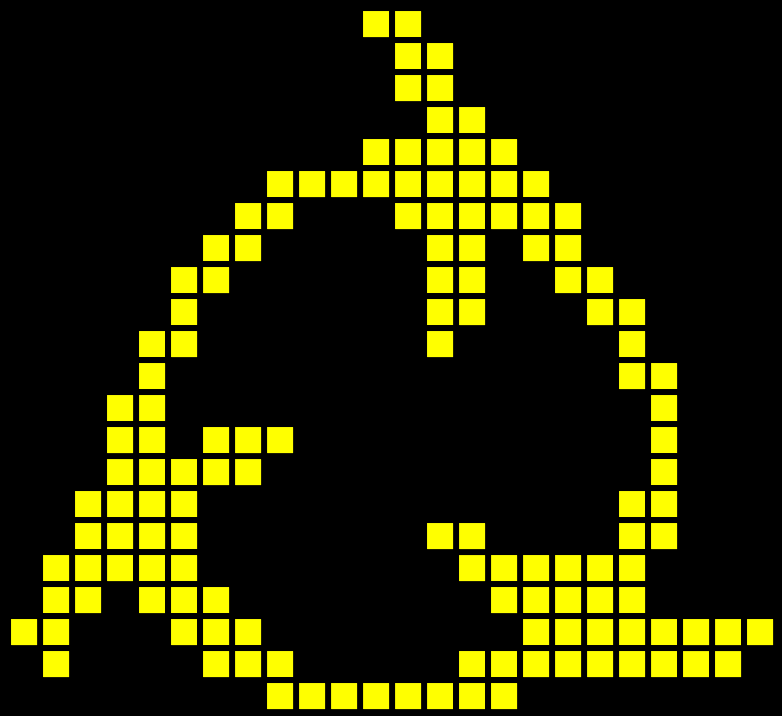
- Layer negative geometry is support
  - Either:
    - Different sacrificial material
    - Or same material in powder form
    - Or same material with weaker structure

Scan Patterns

Vector-scan



Raster-scan

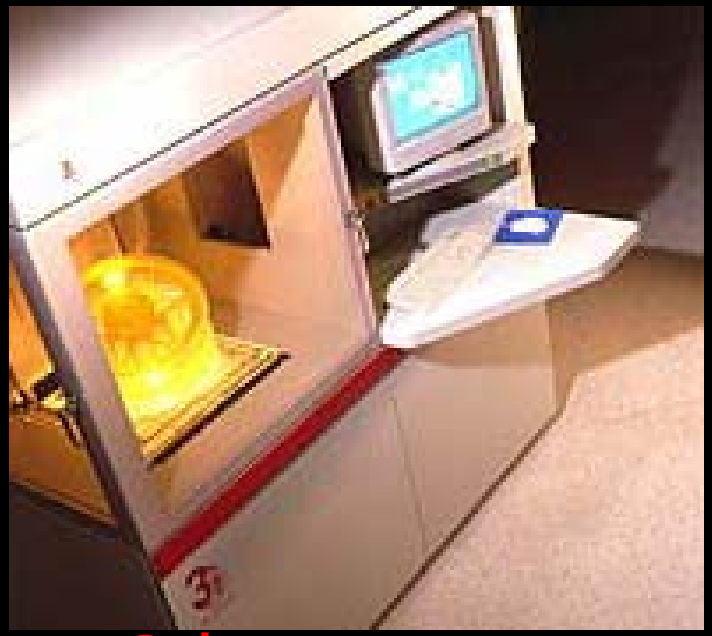


Process Techniques

- Photopolymers
  - Photolithography (vector)
  - Photo-masking (raster)
- Thermoplastic Deposition
  - Extrusion (vector)
  - Ink-jet (raster)
- Lamination
- Powder based
  - Sintering (vector)
  - 3D Printing (raster)

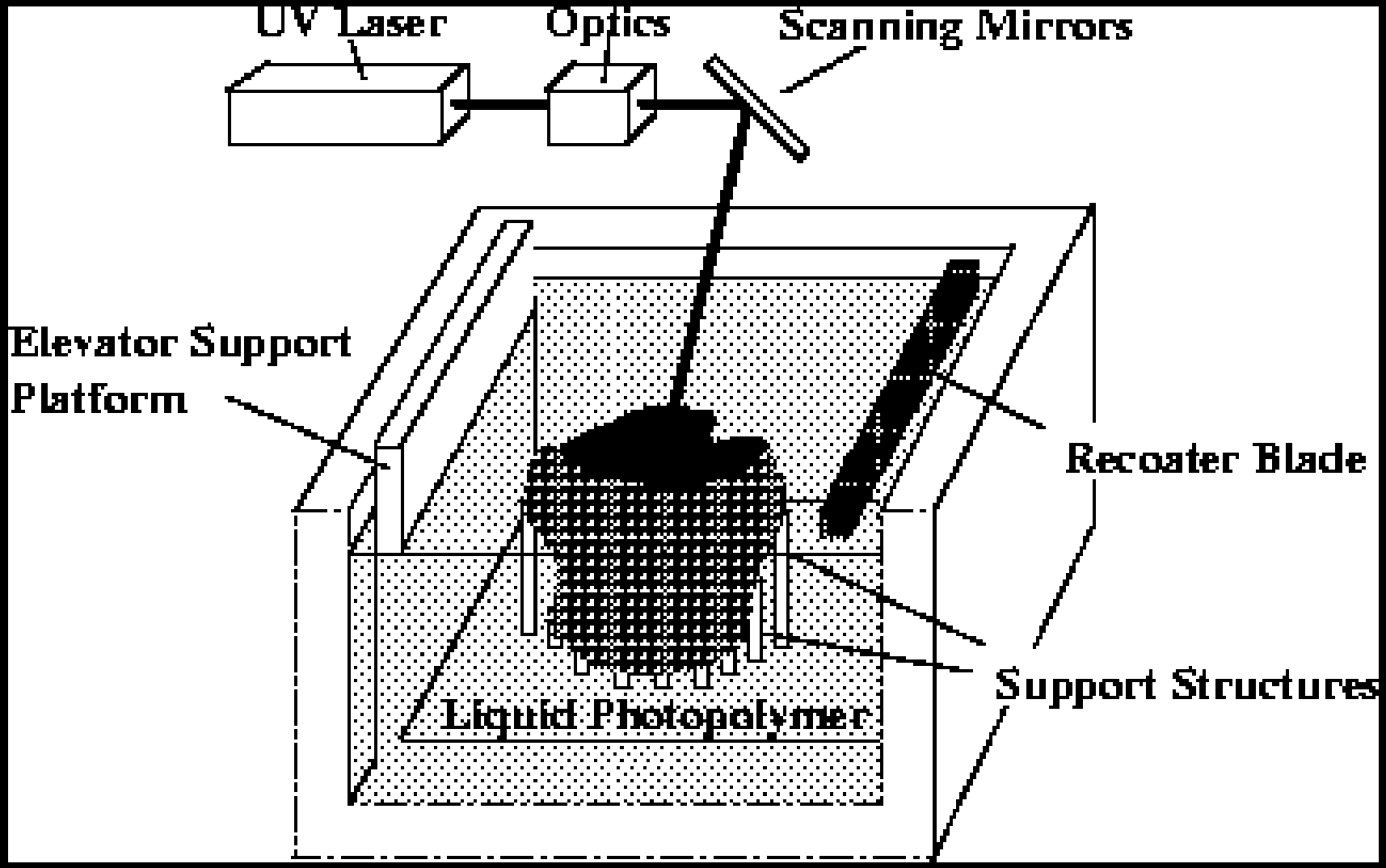
Stereolithography (SLA)

- First commercial layered manufacturing technology (1988)
- Photo-curable liquid resin



- www.3dsystems.com

Stereolithography



Stereolithography

- Pre-process
  - Orient part
  - Choose slice thickness
  - Slice parts and plan supports

Stereolithography

- Process
  - Position build platform just below liquid resin surface
  - Smooth surface with recoater blade
  - Scan layer outline, loose hatch layer interior with laser
  - Lower build platform for next layer

Stereolithography

- Post-process
  - Raise part to drain liquid
    - (except liquid trapped by loose hatch)
  - Remove supports
  - Rinse in isopropanol, water
  - Dry with air hose
  - Post-cure in UV oven

Stereolithography

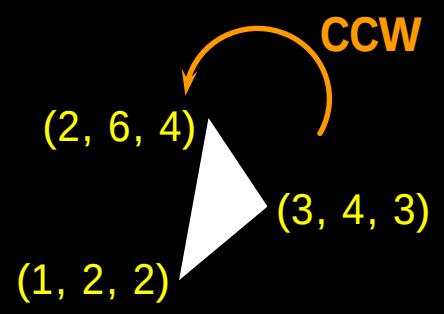
- Characteristics
  - Slow
  - Supports must be removed by hand
  - Lab environment necessary
  - Trained operator
  - Lasers expensive
  - Little material choice
  - Parts can be brittle, fragile

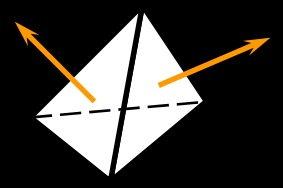
Stereolithography

- Characteristics
  - High accuracy
    - Layer thickness .001-.006”
    - Minimum feature size .003-.012”
  - Large build volume
    - Up to 20x20x23”
  - Investment casting build styles
  - Brittleness useful for certain tooling

The STL Format

- De-facto industry standard
- Boundary representation
- Triangular facets
  - Explicit vertex coordinates (not shared)
  - Counter-clockwise enumeration
- Surface normal for each facet
  - Points to exterior of object (supposedly)





STL File of a Cube

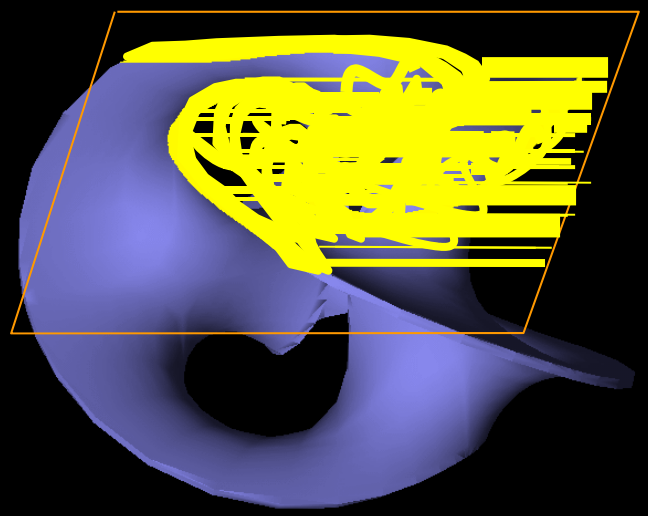
```
solid ascii
  facet normal 1.000000e+00 0.000000e+00 0.000000e+00
    outer loop
      vertex 1.000000e+00 -1.000000e+00 -1.000000e+00
      vertex 1.000000e+00 1.000000e+00 -1.000000e+00
      vertex 1.000000e+00 1.000000e+00 1.000000e+00
    endloop
  endfacet
  facet normal 1.000000e+00 -0.000000e+00
0.000000e+00
    outer loop
      vertex 1.000000e+00 -1.000000e+00 1.000000e+00
      vertex
      vertex
    endloop
  endfacet
  facet normal 0.000000e+00 0.000000e+00 1.000000e+00
    outer loop
      vertex -1.000000e+00 -1.000000e+00 1.000000e+00
      vertex 1.000000e+00 -1.000000e+00 1.000000e+00
      vertex 1.000000e+00 1.000000e+00 1.000000e+00
    endloop
  endfacet
  facet normal -0.000000e+00 0.000000e+00 1.000000e+00
    outer loop
      vertex -1.000000e+00 1.000000e+00 1.000000e+00
      vertex -1.000000e+00 -1.000000e+00 1.000000e+00
    endloop
  endfacet
  facet normal 0.000000e+00 -1.000000e+00 0.000000e+00
    outer loop
      vertex -1.000000e+00 -1.000000e+00 -1.000000e+00
      vertex 1.000000e+00 -1.000000e+00 -1.000000e+00
      vertex 1.000000e+00 -1.000000e+00 1.000000e+00
    endloop
  endfacet
  facet normal 0.000000e+00 -1.000000e+00 0.000000e+00
    outer loop
      vertex -1.000000e+00 -1.000000e+00 1.000000e+00
      vertex -1.000000e+00 -1.000000e+00 -1.000000e+00
    endloop
  endfacet
  facet normal 0.000000e+00 0.000000e+00 1.000000e+00
    outer loop
      vertex -1.000000e+00 -1.000000e+00 1.000000e+00
      vertex 1.000000e+00 -1.000000e+00 1.000000e+00
      vertex 1.000000e+00 1.000000e+00 1.000000e+00
    endloop
  endfacet
```

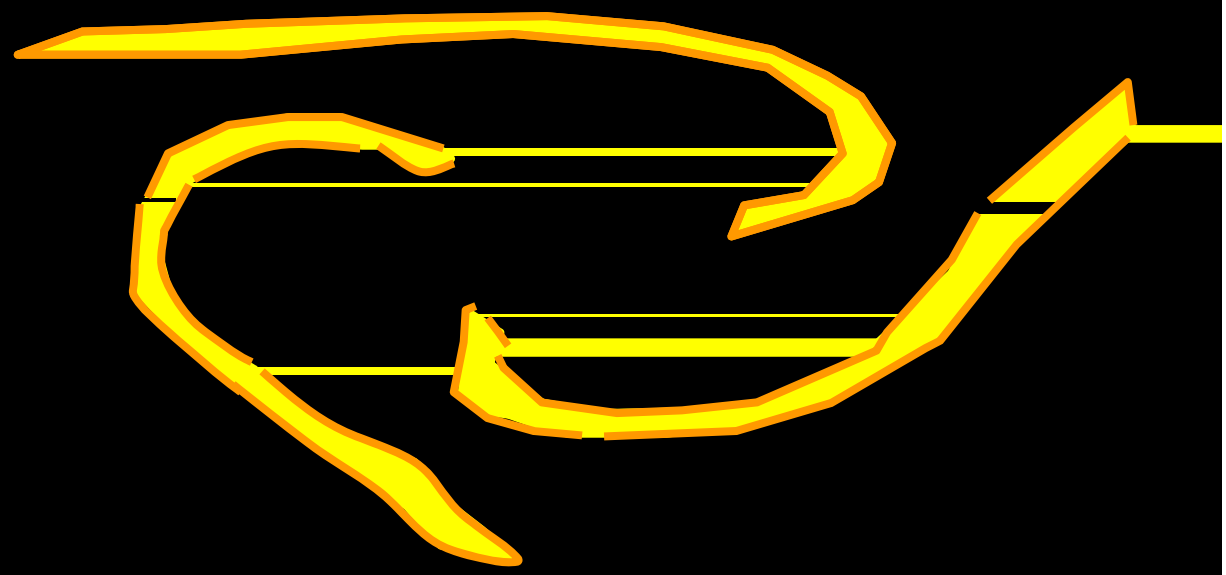
STL Shortcomings

- Redundant
  - Repeats vertex coordinates
  - Exterior specification
- No way to specify solid or surface properties
- No units
- No connectivity (“topology”) information
  - Designer’s intent unclear
  - Cracks

Scanning

- When a good build goes bad…

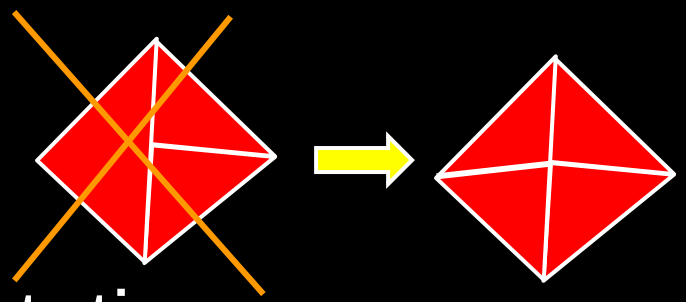




Slice 463

Model Requirements

- Water-tight boundary
  - No cracks
- No T-junctions
  - Vertex-to-vertex rule



- Consistent triangle orientations
- Positive coordinates
  - Some systems automatically translate part