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

- Scientific Visualization
- Topological Models
- Tactile Mathematics

San Diego Harbor
(Mike Bailey)

Hyperbolic paraboloid 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
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

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<th>Normal Vector</th>
<th>Vertices</th>
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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

1.1234569
1.1234570
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