3D Printing

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Variability Expedition

3D printing

- Fabrication methods used to print 3D objects, by depositing material layer by layer

Medical Applications

Architecture

Textile: On-demand clothing

Aeronautics

Pictures from https://futurism.com/3-d-printed-prosthetics-can-turn-person-sci-fi-god/, https://www.sculpteo.com/en/applications/,

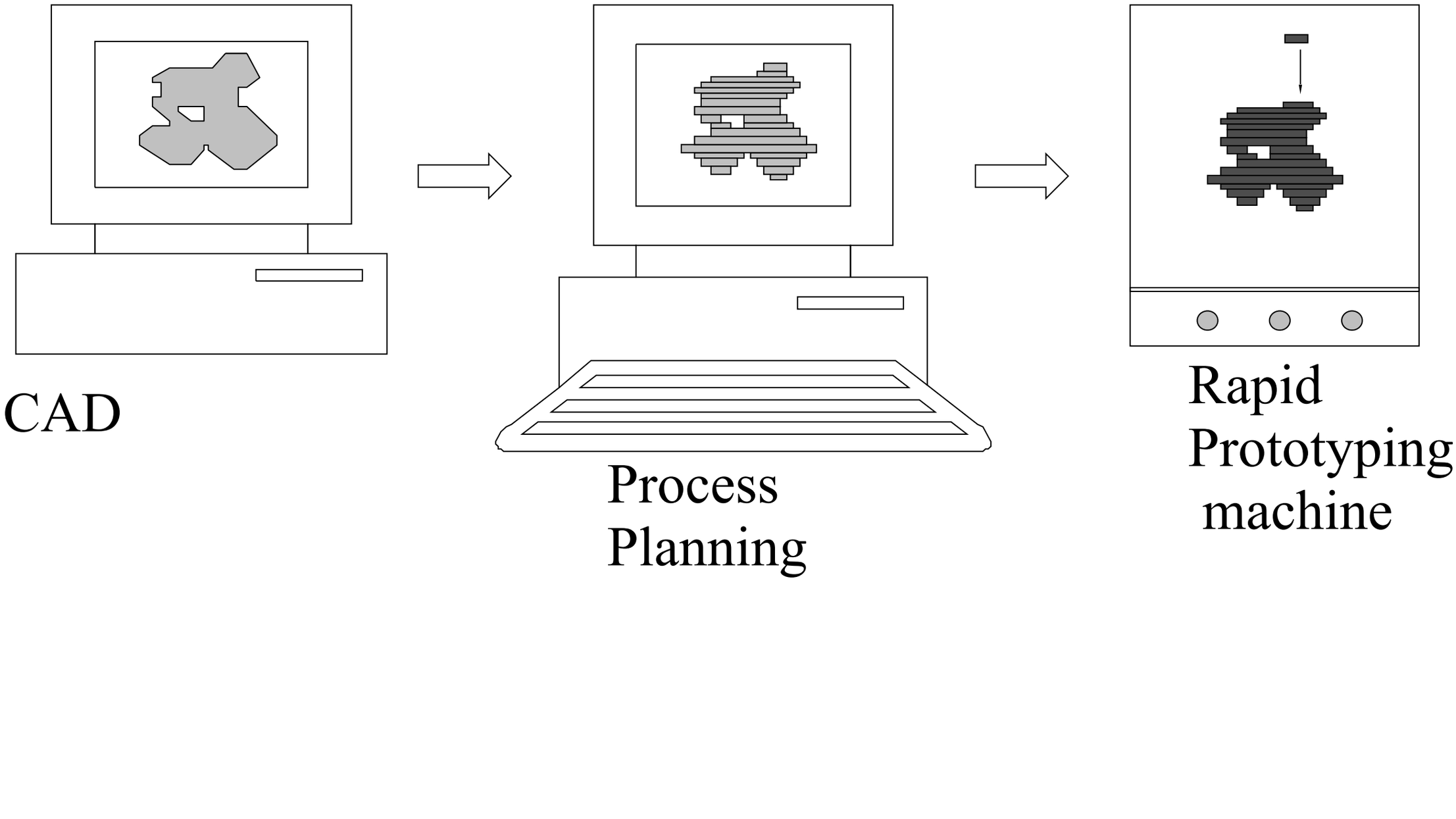
Why 3D printing?

- Fast turn – around

- Cost – effective!

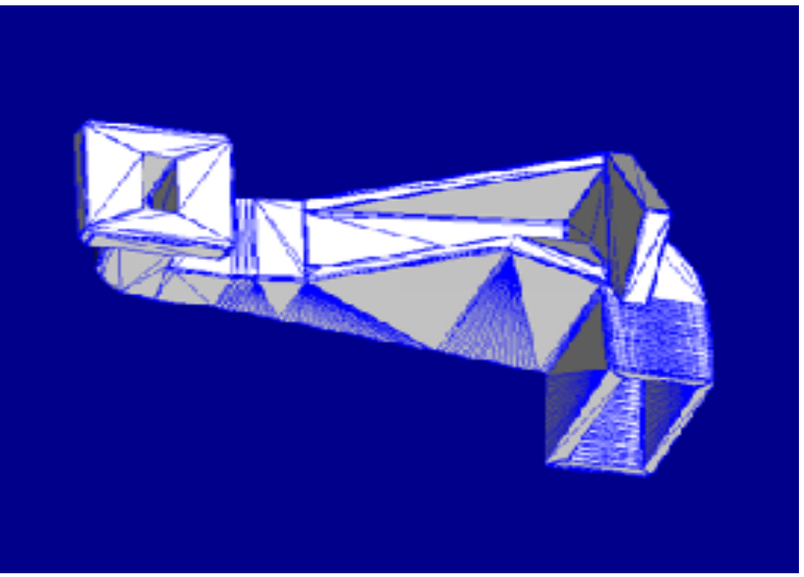
What is 3D printing flow like?

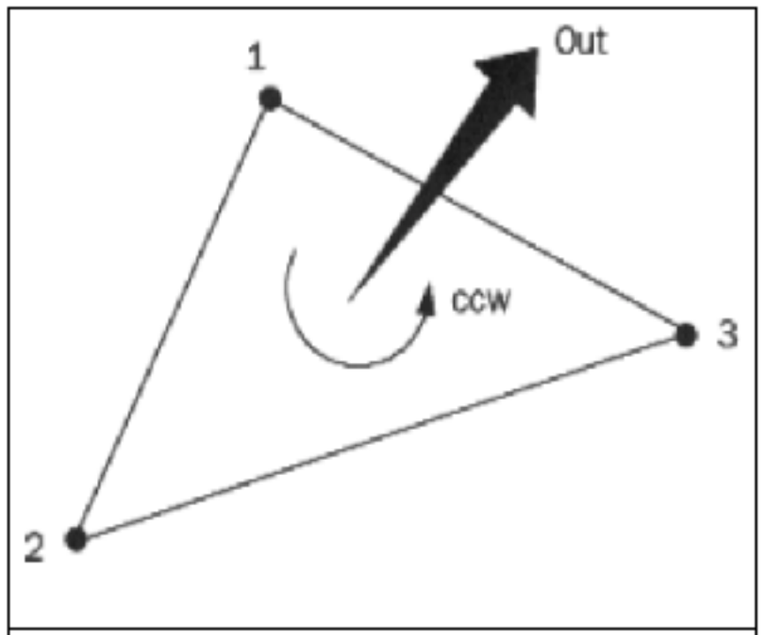
- a.k.a Rapid Prototyping (RP), Layered Manufacturing (LM)



Object representation: .STL FILE

- STL: STereoLithography
- Representation of the surface geometry of a 3d object
- Triangles
  - For each triangle: X, Y, Z coordinates of the three vertices, and the surface normal





Orientation of a facet is determined by the direction of the unit normal and the order in which the vertices are listed.

solid *name*

$$\left\{\begin{array}{l}\textbf{facet normal } n_i\ n_j\ n_k \\ \quad \textbf{outer loop} \\ \quad\quad \textbf{vertex } v1_x\ v1_y\ v1_z \\ \quad\quad \textbf{vertex } v2_x\ v2_y\ v2_z \\ \quad\quad \textbf{vertex } v3_x\ v3_y\ v3_z \\ \quad \textbf{endloop} \\ \textbf{endfacet}\end{array}\right\} +$$

endsolid *name*

Source: http://www.fabbers.com/tech/STL_Format

Different types of 3D printing

1. Stereolithography (SLA)
2. Fused Deposition Modeling (FDM)
3. Digital Light Processing (DLP)
4. Selective Laser Sintering (SLS)
5. Binder Jetting (BJ)

1. Stereolithography

- First commercial RP
  - By 3D systems', Valencia C
- UV Laser traces a cross-sectior of the part on the surface of the liquid resin
- Exposed resin solidifies and joins layer below

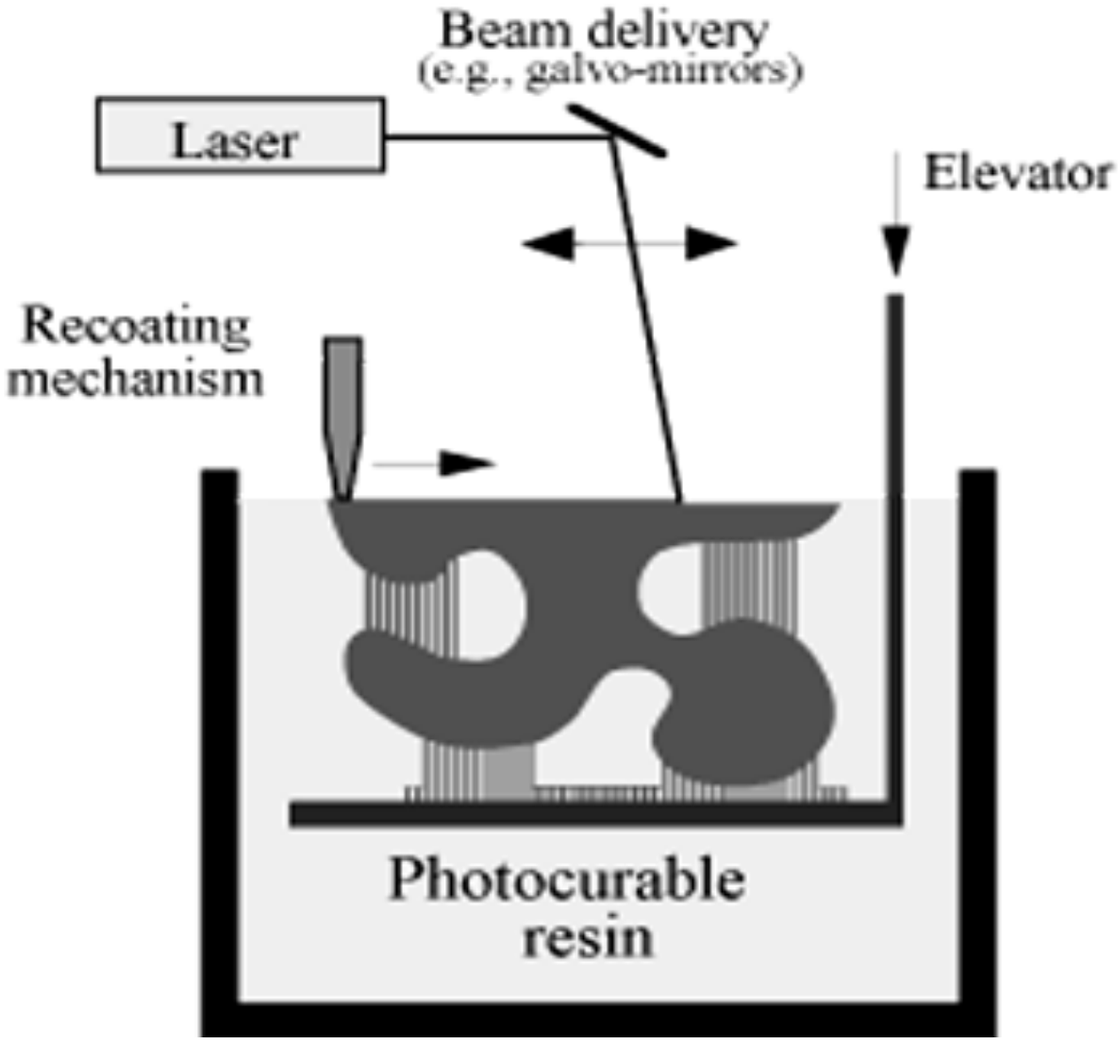
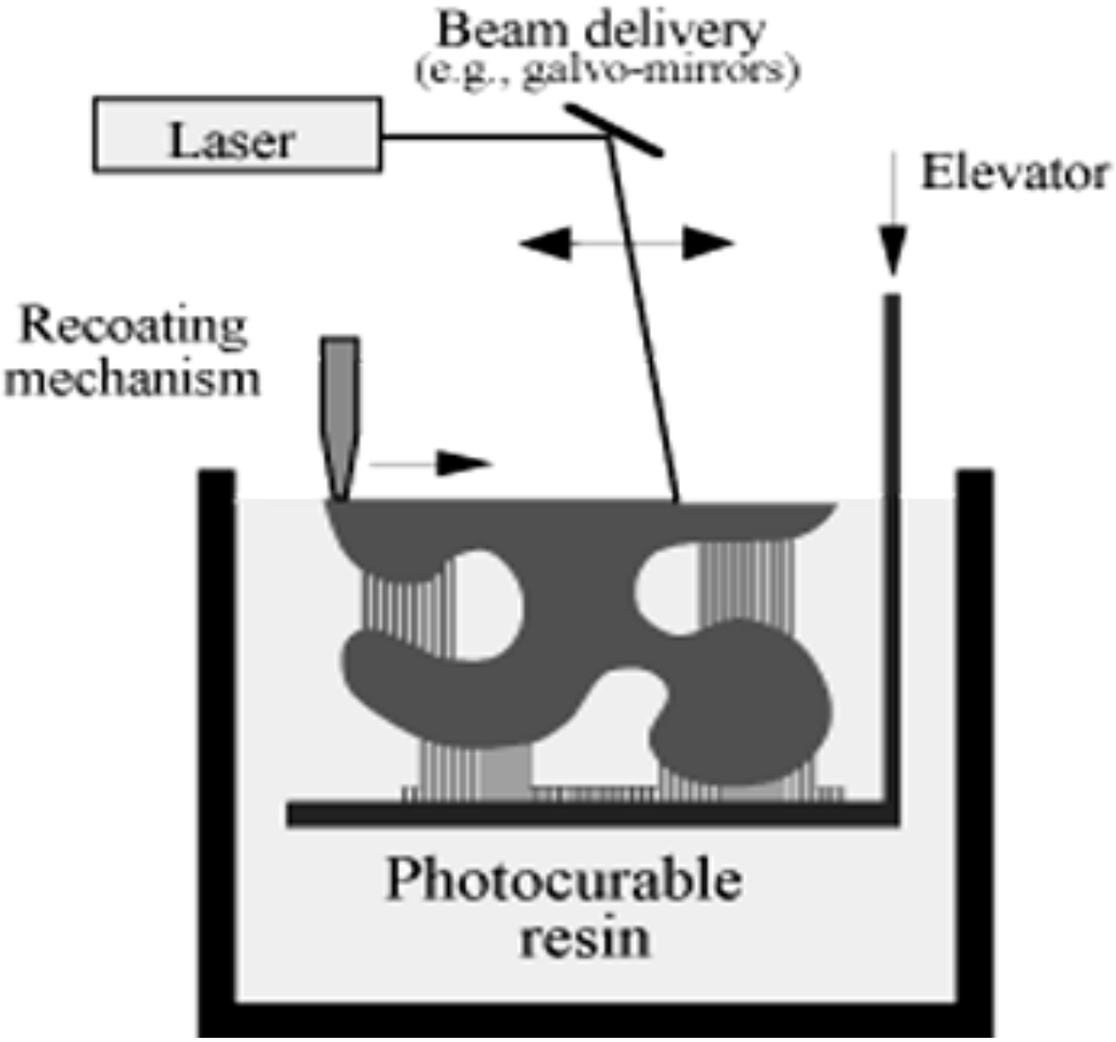


Image from Professor Xiaochun Li's slides, MAE298, UCLA

1. Stereolithography

- To build next layer:
  - SLA's elevator platform descends by a distance equal to thickness of a single layer
  - A resin-filled blade re-coats it with fresh material.



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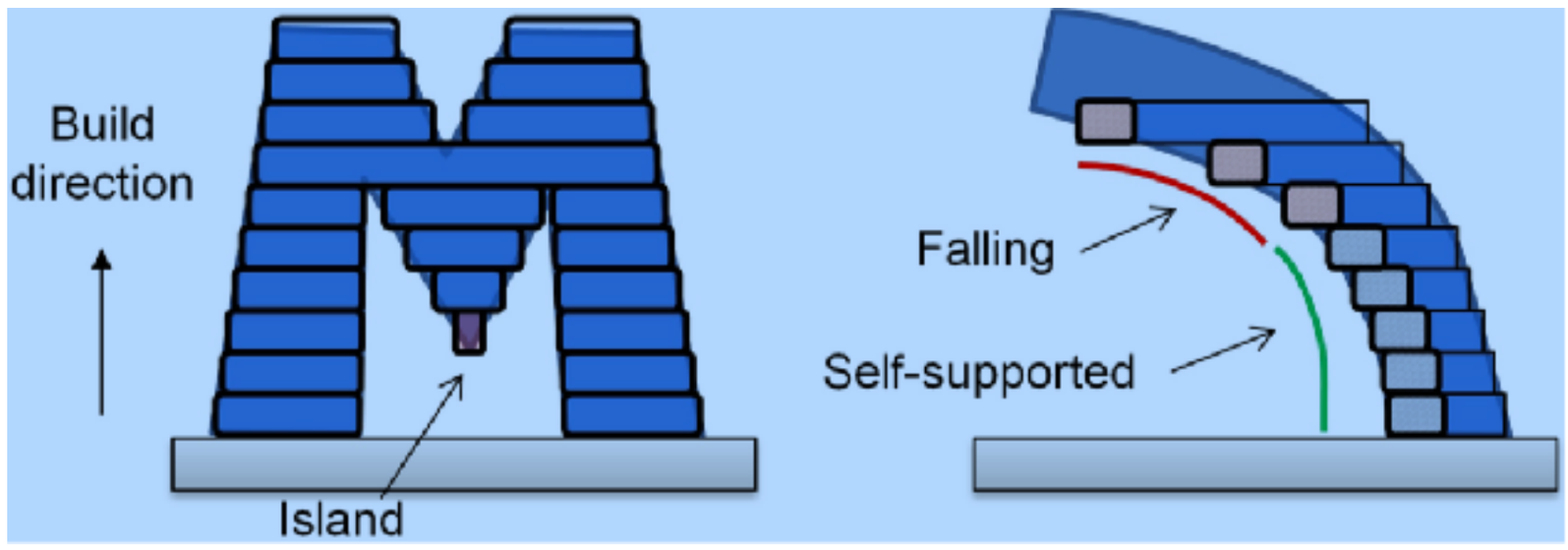
Support Structures for SLA

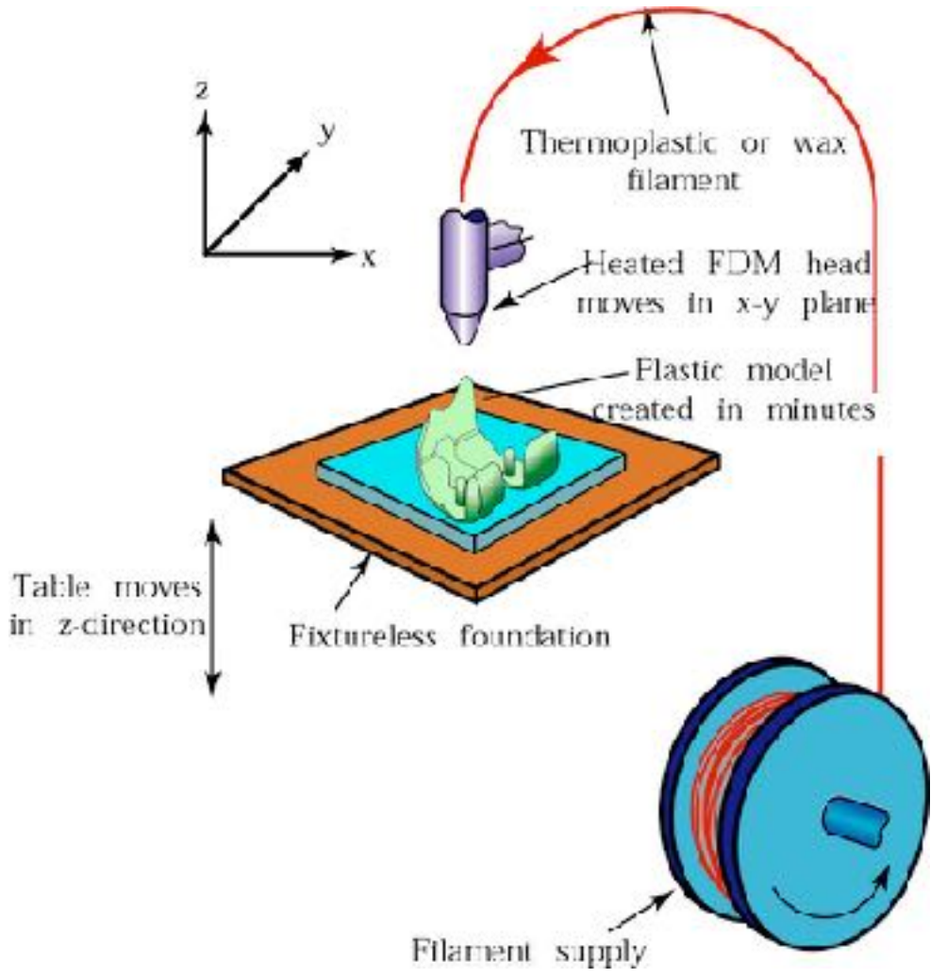
- SLA sometimes requires supporting structures to attach part to elevator platform
- Removed in post-processing

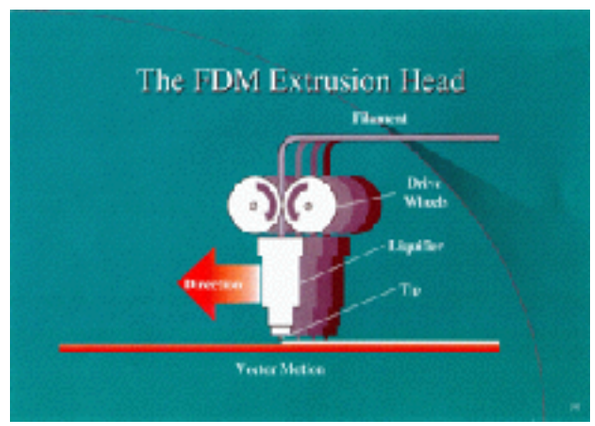


Source: https://arxiv.org/pdf/1705.03811.pdf

2. Fused Deposition Modeling (FDM)

- FDM is the most common desktop 3D printing method.
- Thermoplastic filament is heated and extruded through a head that deposits the molten plastic in X and Y coordinates
- The build platform lowers the object layer by layer in the Z direction.

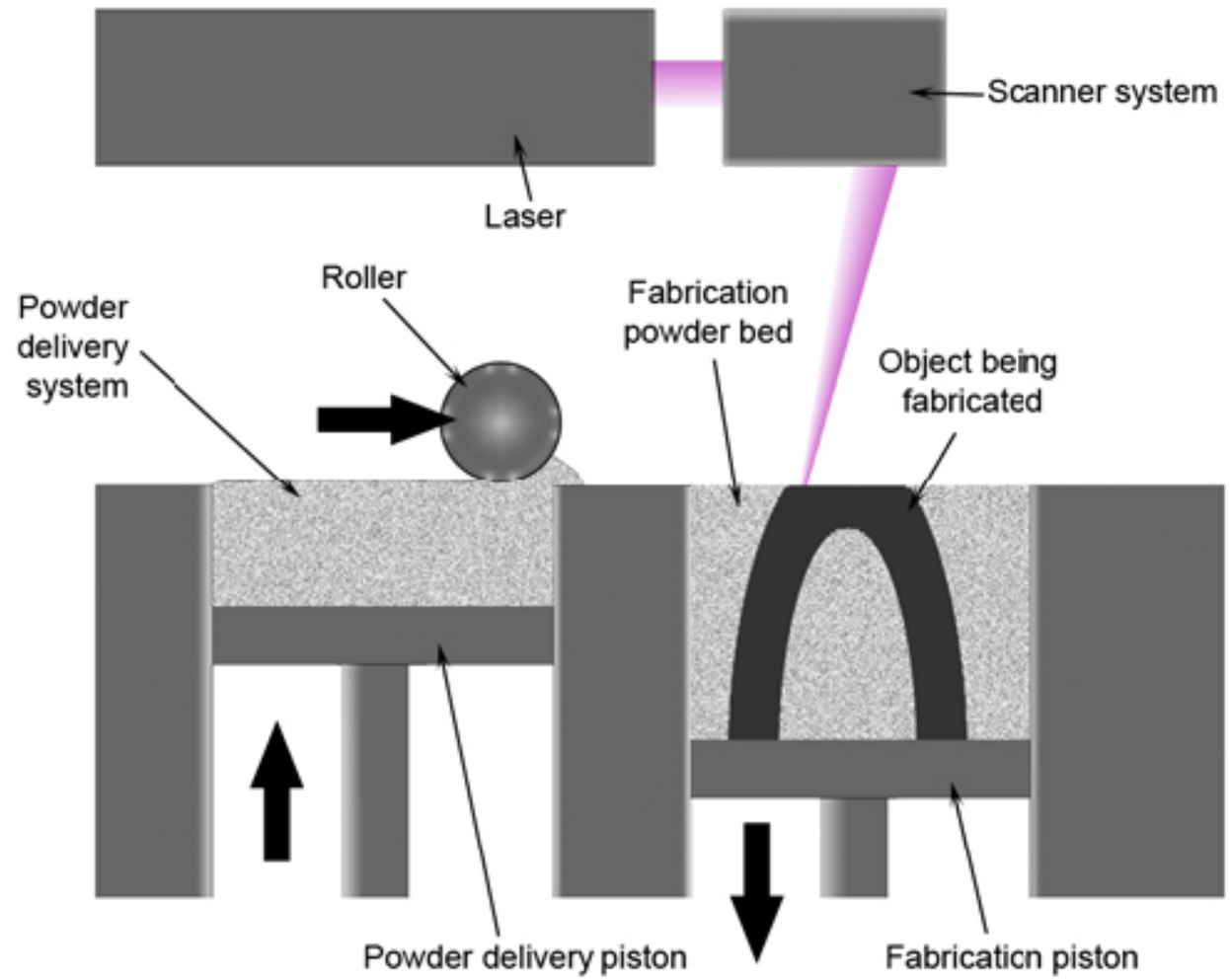




Images from Professor Xiaochun Li's slides, MAE298, UCLA

3. Selective Laser Sintering (SLS)

- SLS is similar to SLA, but uses powdered material instead of liquid resin.
- Laser is used to selectively sinter a layer of granules, which binds the material together to create a solid structure.
- Similar process used for metals



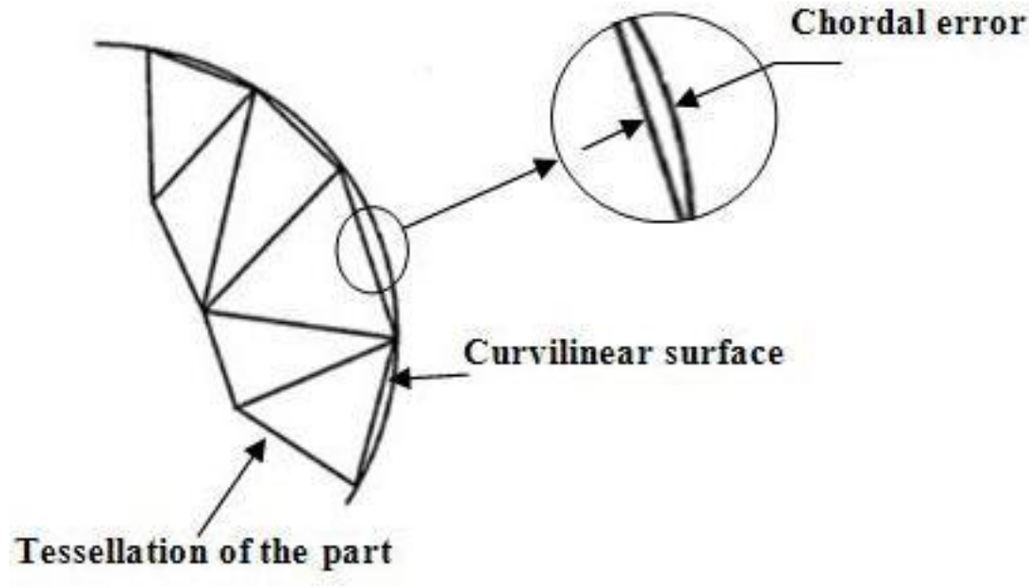
https://en.wikipedia.org/wiki/Selective_laser_sintering

Chordal Error

- **Tesselation of object**:
  - tiling a surface with geometric shapes such that there are no overlaps or gaps.

- Chordal error: Defect due to tesselation

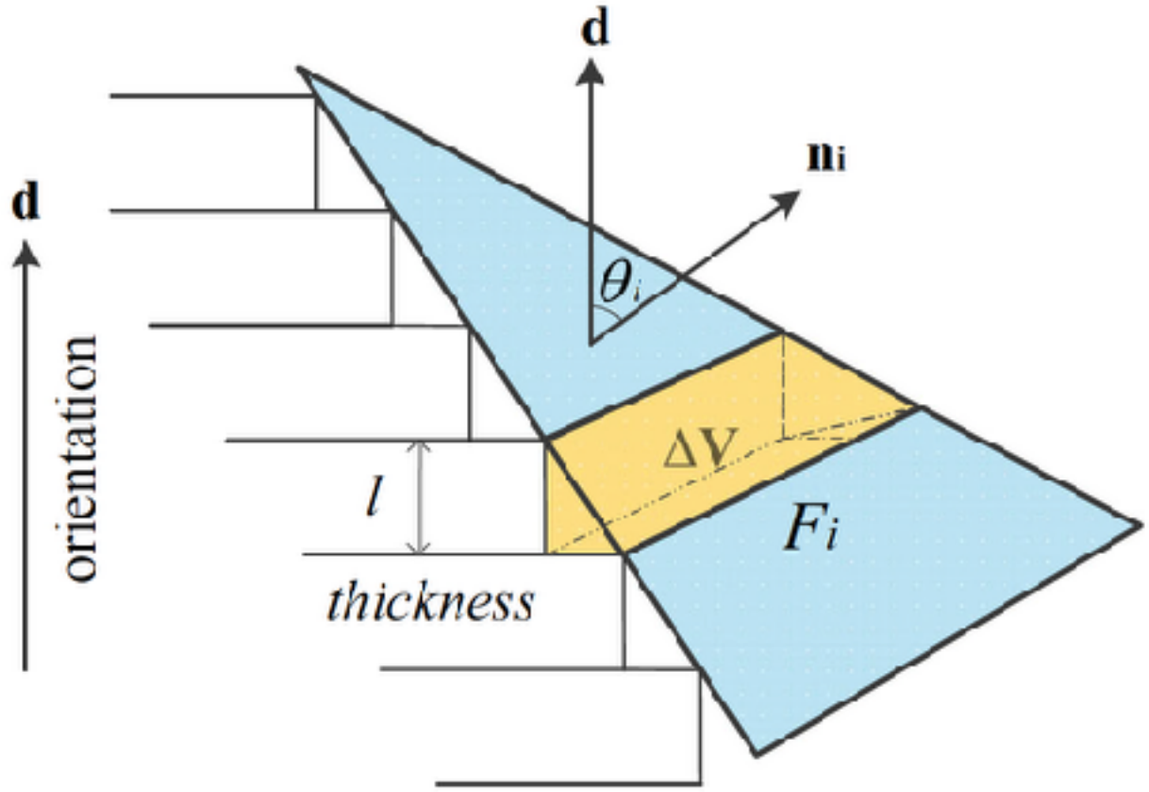
- To reduce chordal error:
  - Increasing number of triangles → increase computational complexity



Source: Taufik et al; 2014

Staircase Error

- Volumetric error
  - Between the model and printer object



(a) Slicing of facet

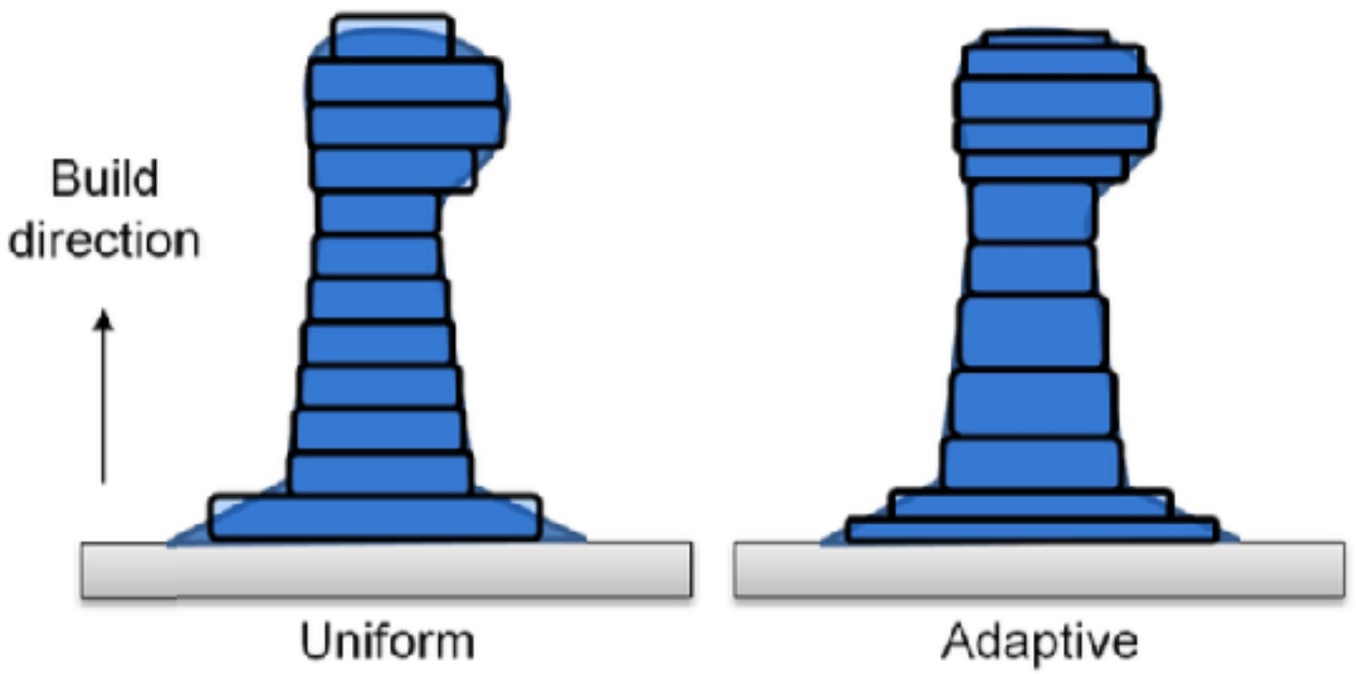
Source: Luo et al; 2014

Selecting orientation

- **Orientation affects:**
  - Surface quality
    - If Build direction is parallel to objects edges→no staircase error
  - Time needed to print object
    - Fewer layers→shorter print time
  - Amount of support structures needed
    - Orientation determines the overhang in the objects and the islands

Slicing

- **Uniform Slicing**
  - One slice thickness used throughout the whole object
  - Tradeoff between accuracy and printing time
- **Adaptive Slicing**
  - Small thickness where high accuracy is needed
- Thicker slice
  - Faster



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Requirements for Project

1. Download software for the Formlabs 3D printer (Form1+/Form2): preform
   https://formlabs.com/tools/preform/

2. Download numpy-stl and tqdm

OSX:

sudo easy_install pip
pip install numpy-stl
conda install tqdm

Windows:

pip install numpy-stl
conda install tqdm

Assignment: Rotate the lion

- Open Preform.
- Load SimpleLion.stl → repair
- In the python code,
  - Rotate the object by 90 degrees aorund X –axis
  - Save the rotated lion as rotatedLion.stl
- Load rotatedLion.stl in Preform→ repair

Project

- **Required**:
  - Find the “best” orientation to print the object
    - Best tradeoff between **printing accuracy** and **printing time**
    - **Metric**: sqrt (number of layers) * ERROR
      - Find angles (x, y, x) to achieve minimum possible metric value

- We will ignore support structures
- Degrees of freedom:
  - 360 degrees rotation around X-axis
  - 360 degrees rotation around Y-axis
  - 360 degrees rotation around Z-axis

- Error Calculation for **one orientation only** takes more than 2 minutes
  - No way to sample all possible orientations for error
  - Figure out a smart way to sample ”enough” orientations

- To calculate error
  - calculateError(stlObj,0.2,5)

Pick an interesting object to print

- Lot of interesting models online for free!
- Models available at https://all3dp.com/1/free-stl-files-3d-printer-models-3d-print-files-stl-download/
- **CONSTRAINT**
  - Printing time < 75 minutes
  - Check time using preform
- We will be printing some of your objects until the end of the program
  - It takes time!

Research/Presentation Topics

1. Adaptive Slicing Algorithm(s)

2. Orientation Selection Algorithm (s)

3. Algorithm(s) to generate support structures

4. Vector vs. Raster-based printers

5. Comparison between commercial printers (personal use and large scale printers)

6. A type of 3D printing
   - Examples: Digital Light Processing (DLP), Binder Jetting (BJ), Continuous Liquid Interface Production (CLIP)