3D Printing / Additive Manufacturing

"The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal.”

Ivan Sutherland

Rapid Prototyping

Technology existed since the 1980s

Rapid Prototyping

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Usually refers to **additive manufacturing**

- as opposed to sculpting, milling, etc

Rapid Prototyping

Technology existed since the 1980s

2009: first MakerBot; now ubiquitous

What changed?

Rapid Prototyping

Technology existed since the 1980s

2009: first MakerBot; now ubiquitous

What changed?

- expiration of key patents
- economy of scale

3D Printers

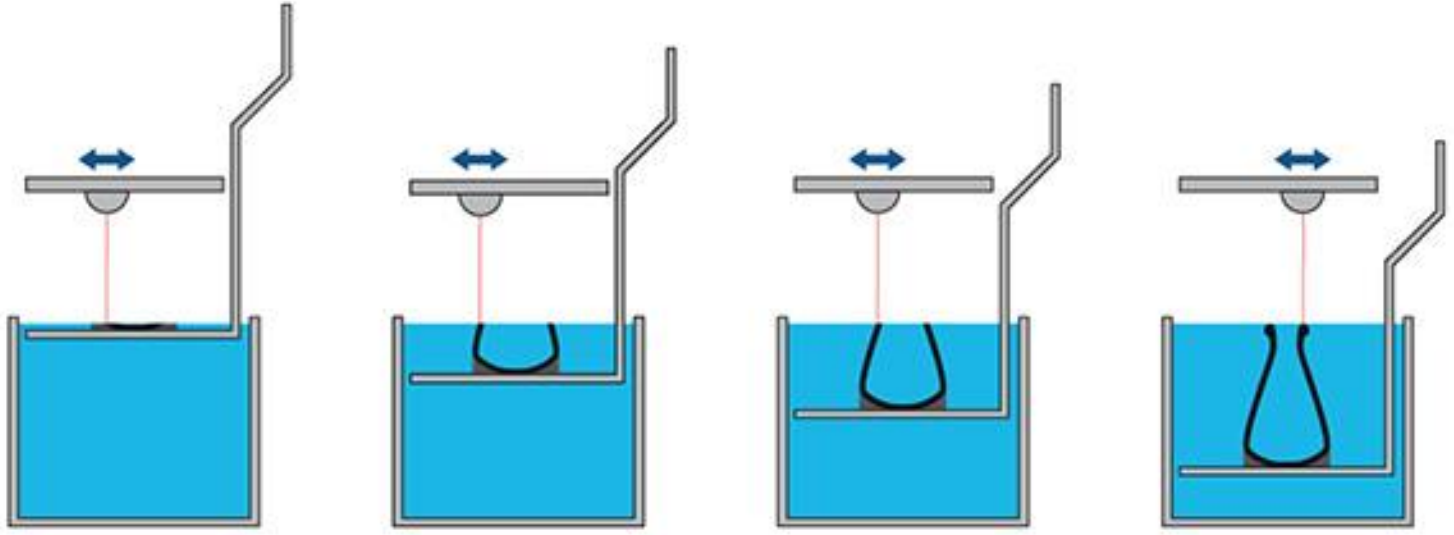
Three main technologies

- stereolithography (Formlabs)
- fused deposition modeling (Makerbot)
- laser sintering (Shapeways plastic)
- lost-wax casting (Shapeways metal)

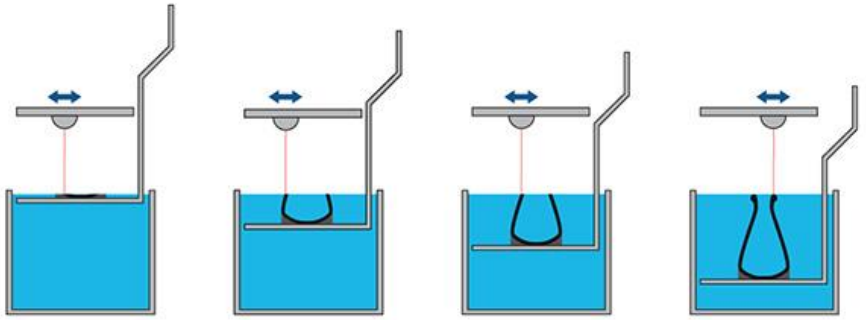
Stereolithography

Vat of liquid that polymerizes (hardens) when hit by UV light

Sweep UV beam over to lay down each cross section

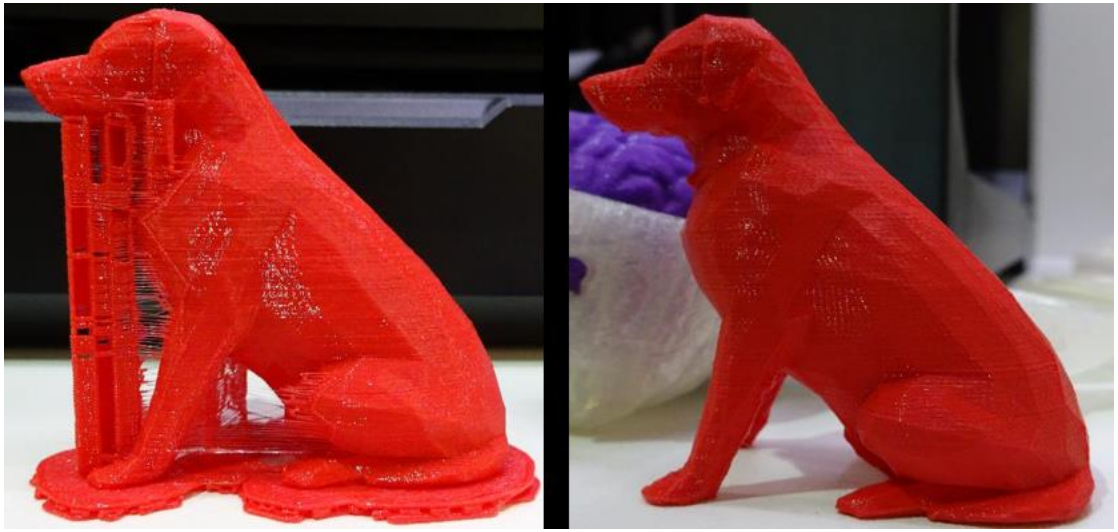


Stereolithography

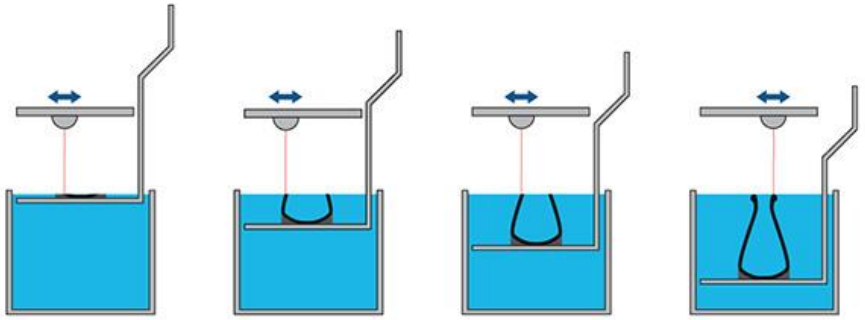


Later layers must be **supported** on top of earlier layers

- overhangs must have **support structure**
- manually removed after printing



Stereolithography



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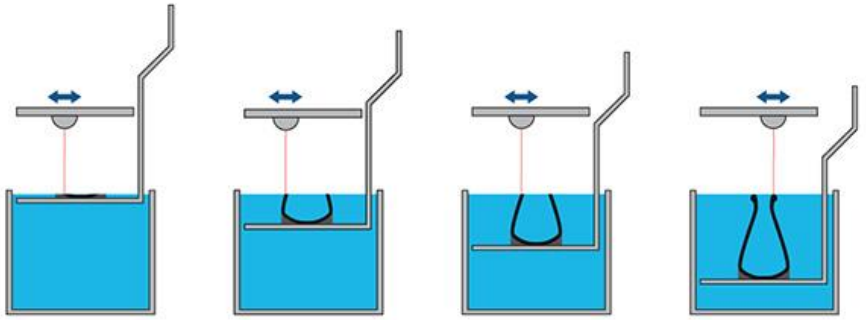
Must be able to drain leftover fluid

Stereolithography



Pros:

- fast
- resulting objects are strong

Cons:

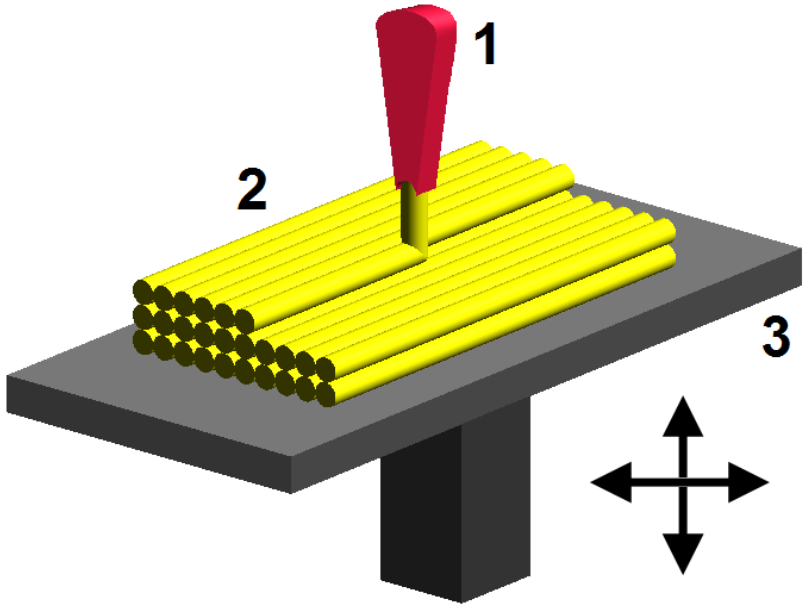
- printer and raw materials expensive
- complicated and messy printing process

Fused Deposition Modeling

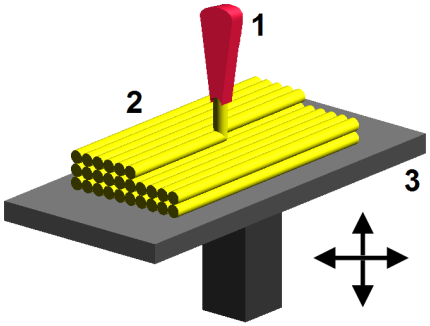
Plastic wire spooled into print head

Melted and extruded through nozzle

Each layer printed using space-filling curve

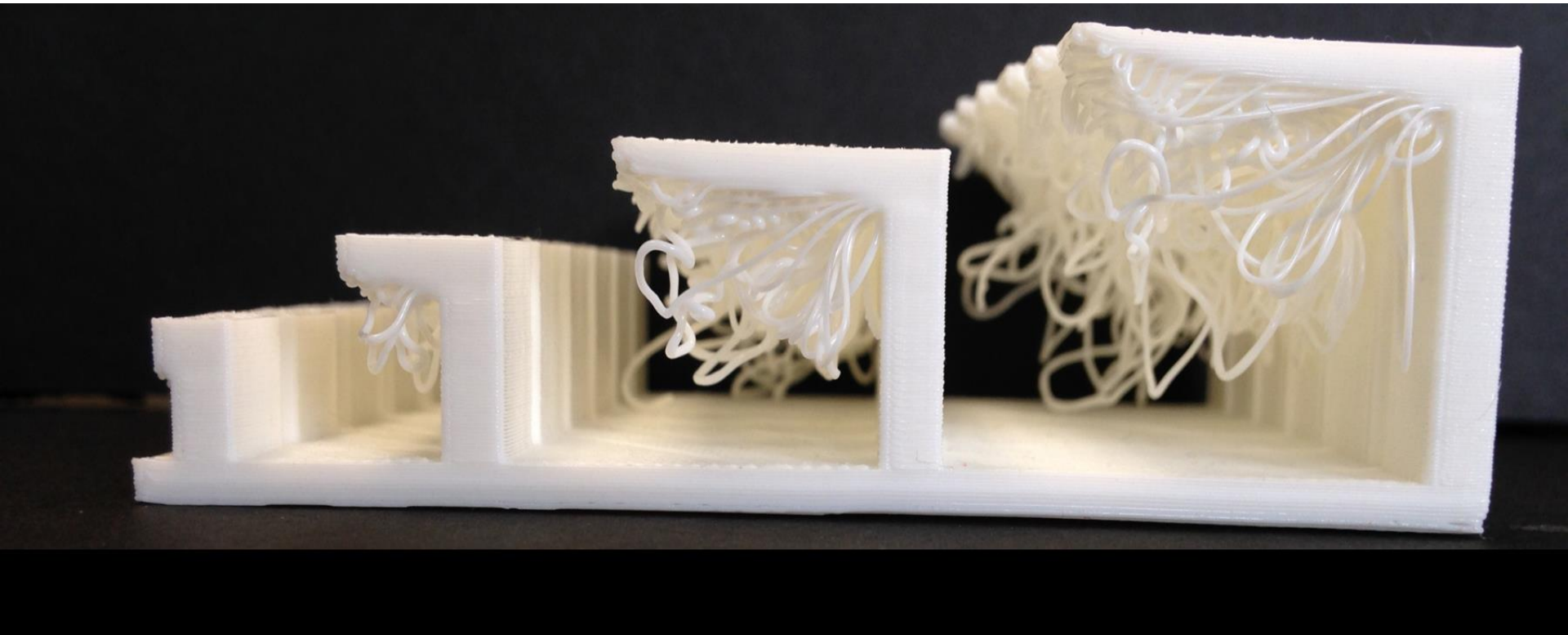


Fused Deposition Modeling



Also needs support material

- overhangs very challenging/noisy



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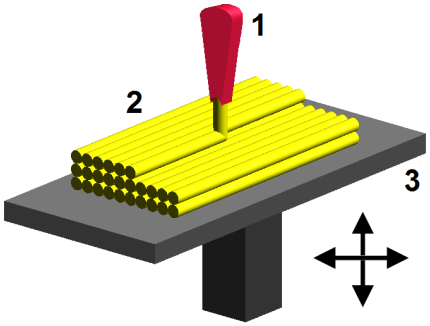


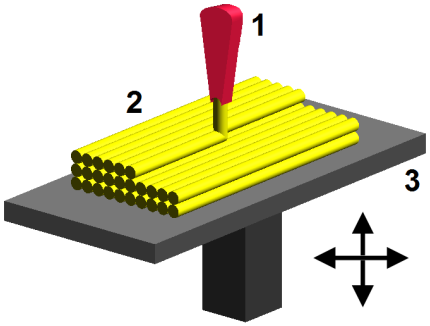
Also needs support material

- overhangs very challenging/noisy

Object must be decomposable into layers made of curves

- no super-thin features
- resulting object has a “grain”

Fused Deposition Modeling



Pros:

- cheap
- easy to use

Cons:

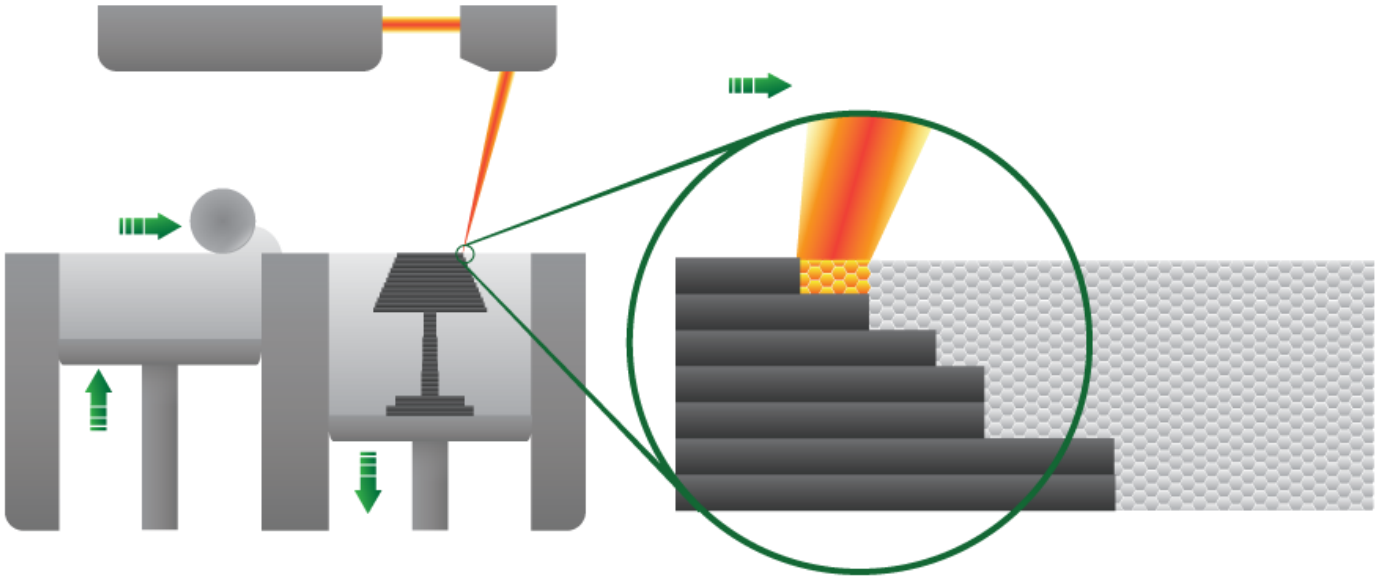
- inaccurate; rough final surface
- limited printing volume

Laser Sintering

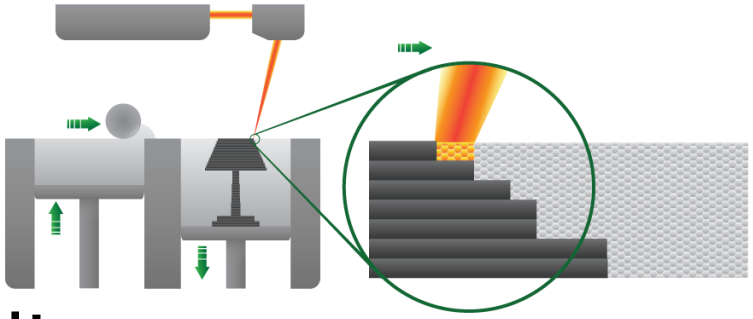
Begin with layer of dry powder

Laser sweeps over powder, fusing regions that will become object

Then add new layer of powder



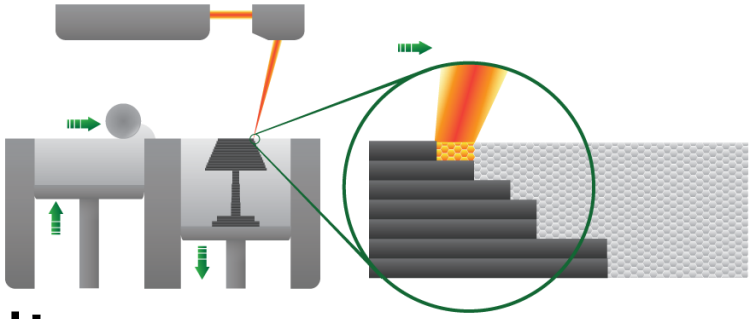
Laser Sintering



No support material needed!

- remaining unfused powder below supports layers above

Laser Sintering



No support material needed!

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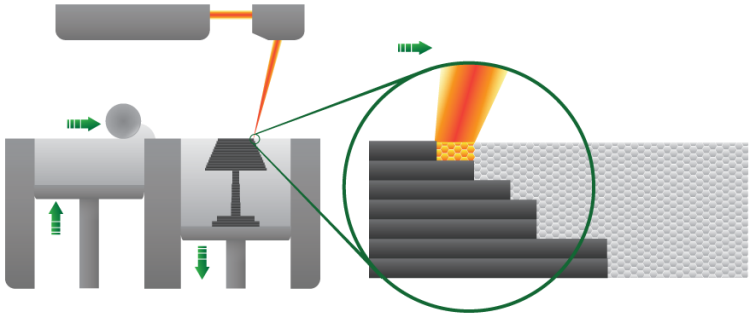
Can color powder before fusing

Powder must be able to drain from object

Laser Sintering



Pros:

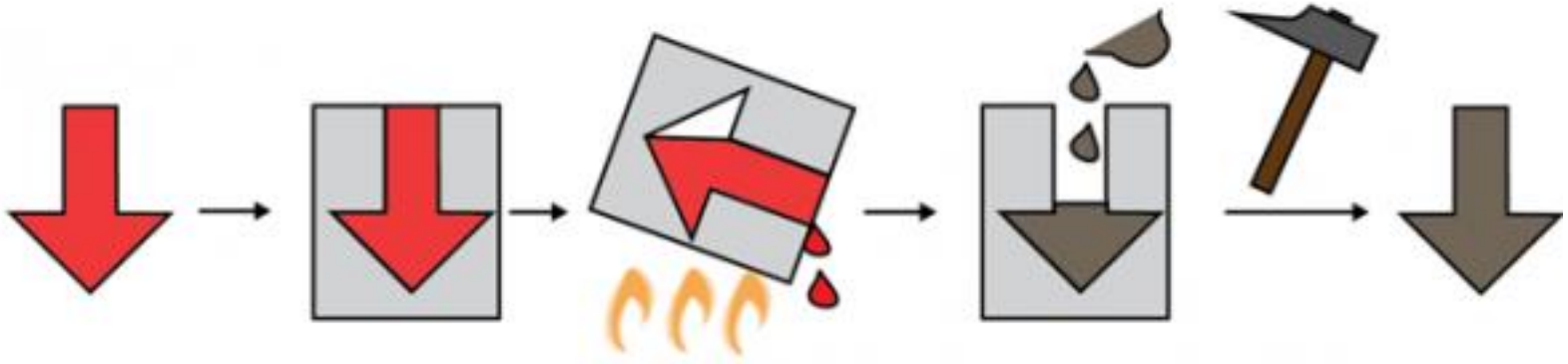
- extremely accurate (microns)
- very flexible: no support material needed

Cons:

- extremely expensive
- complicated printing setup
- limited printing volume

Lost-Wax Casting

1. Print object out of wax
2. Build plaster mold around wax
3. Melt wax
4. Fill mold with molten metal
5. Remove cast



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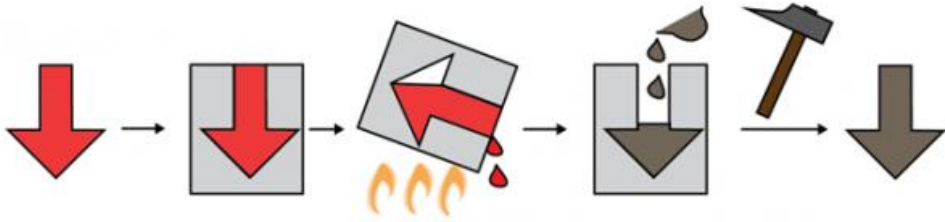

Extremely complicated process…

- but only way to 3D-print metals that cannot be sintered (gold, etc)

3D Printers

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…so what's the Computer Graphics angle?

3D Printing Hype vs Reality

Hype: never buy anything ever again! Print it all at home yourself!

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- they look cool but don’t function

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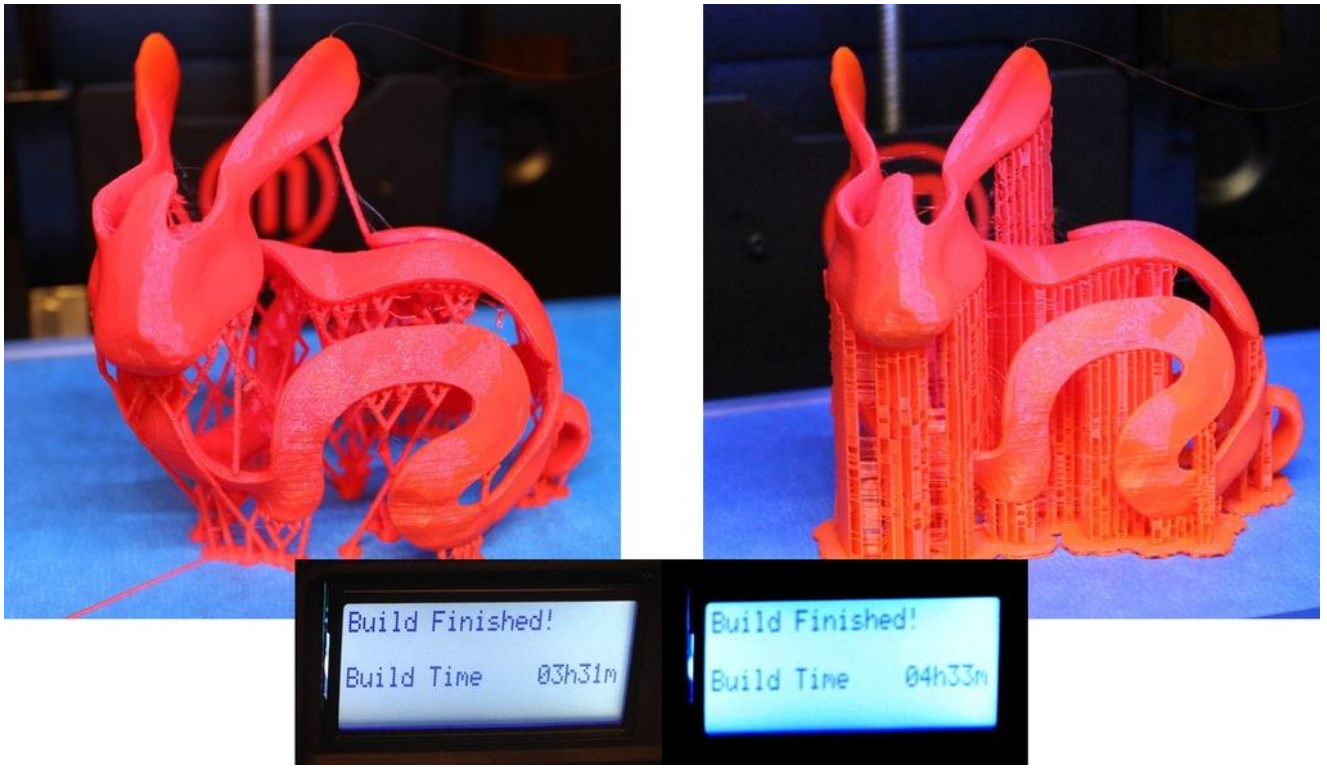
Use software to overcome hardware limits

Optimizing the Printing Process

How can you minimize support material?

Maximize ease of removing it?



Optimizing the Printing Process

Instead of support material, can we decompose object into simpler pieces?

[Hu et al 2012]

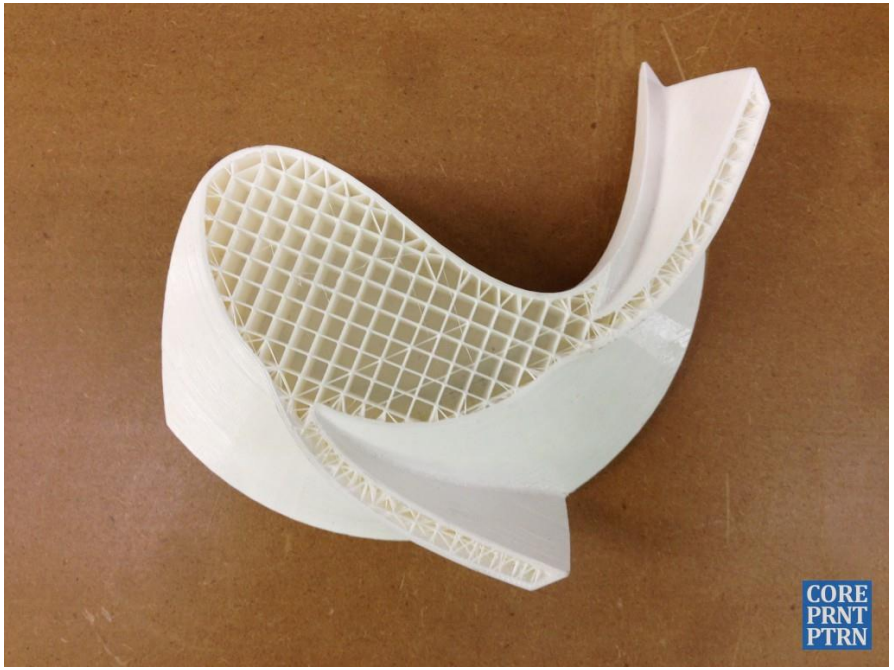
Optimizing the Printing Process

How do we split big objects into printable pieces?

[Luo et al 2012]

Optimizing the Printing Process

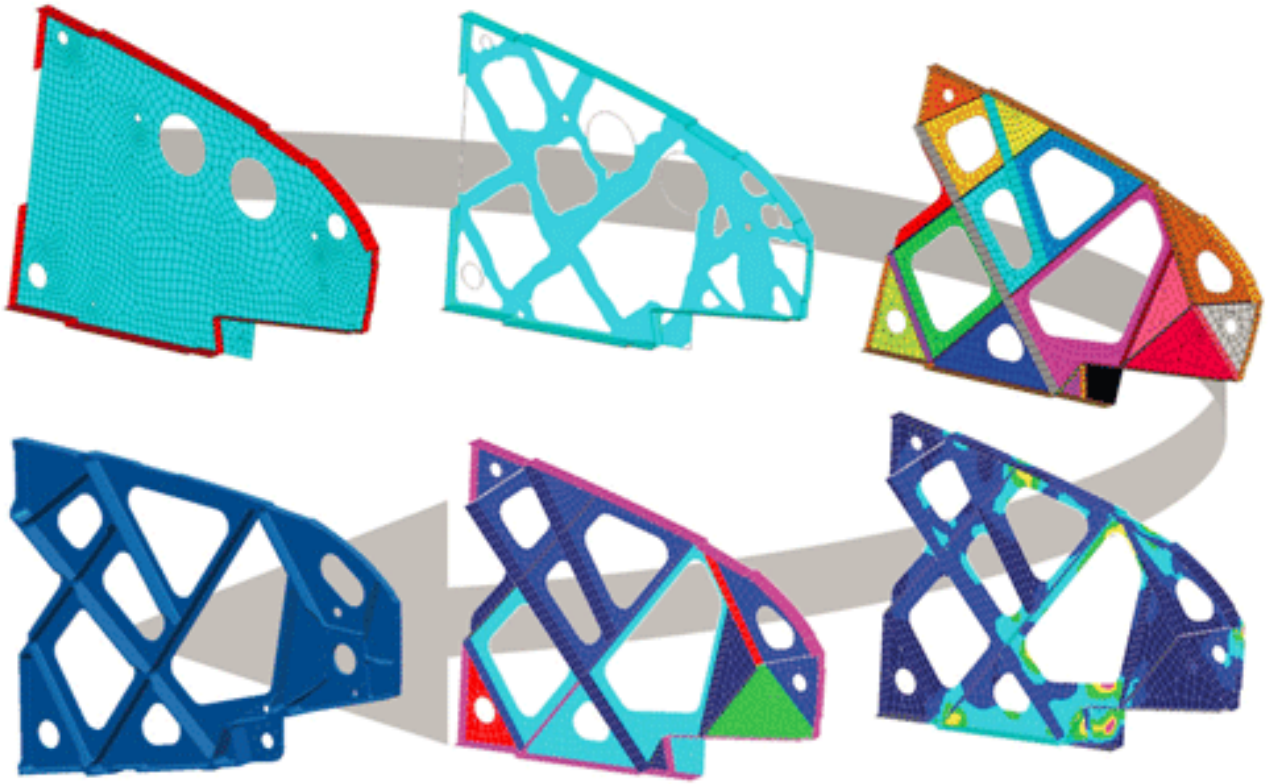
How do we minimize the material used?



Optimizing the Printing Process

How do we minimize the material used?

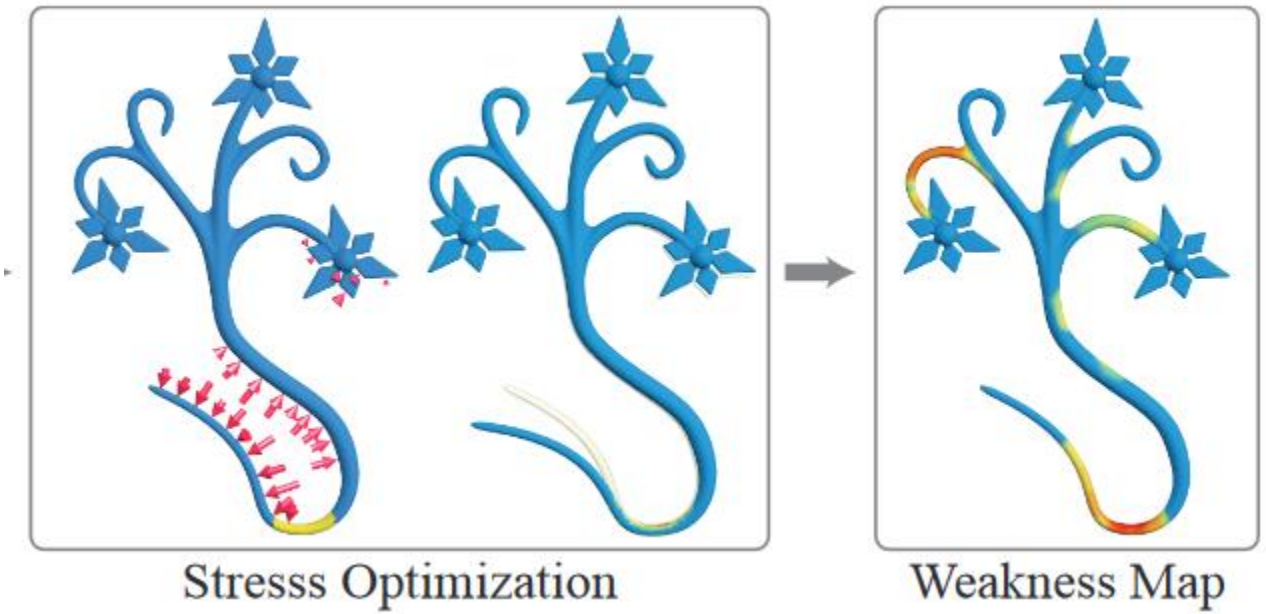
…without compromising strength?



topology optimization

Optimizing the Printing Process

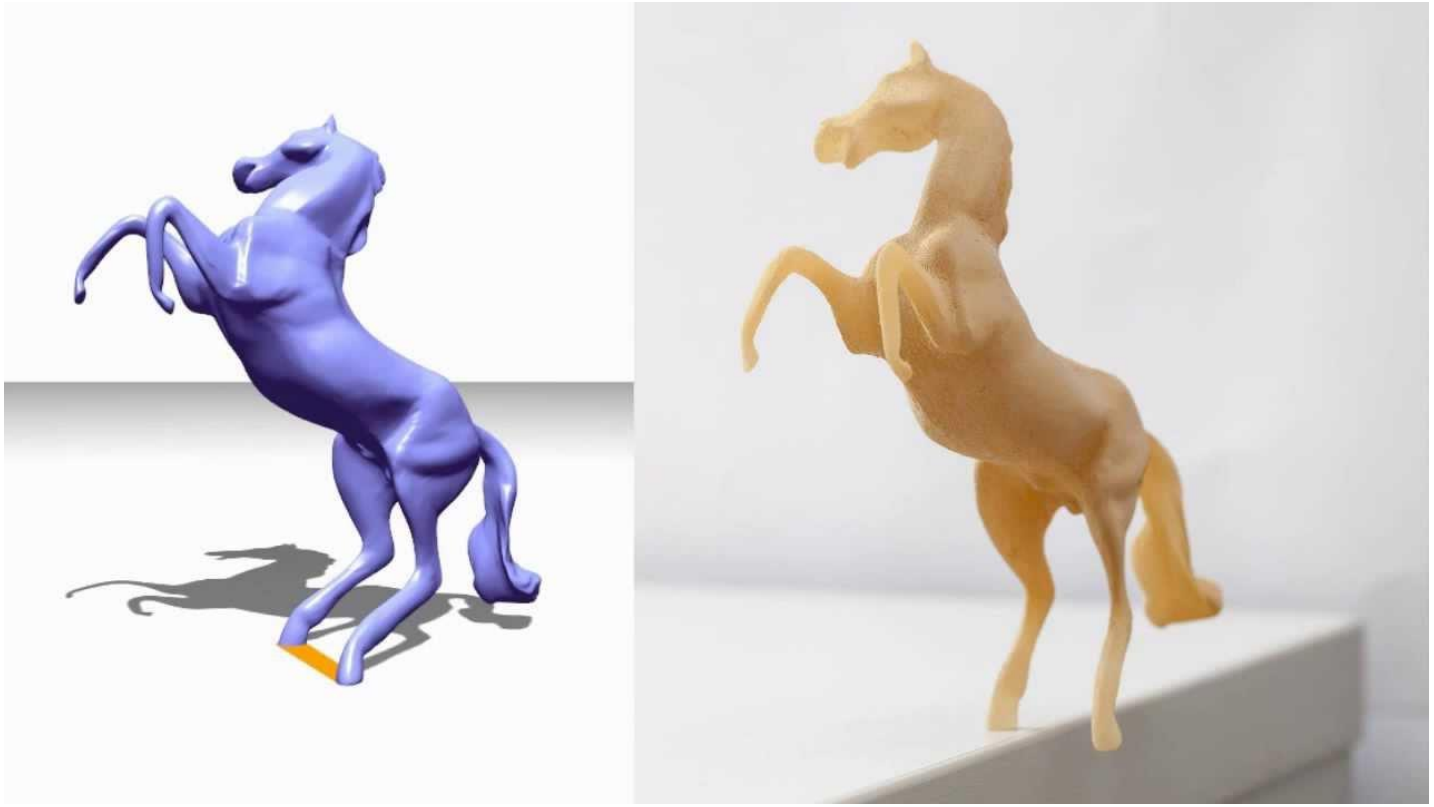
Can we predict where the object will break?



[Zhuo et al]

Optimizing the Printing Process

Can we make objects stand up?



[Prevost et al]

“4D” Printing

How can we make objects not just **look** the way we want, but **act** the way we want?

“4D” Printing

How can we make objects not just **look** the way we want, but **act** the way we want?

Challenges:

- only 1-2 materials available
- weak control over printing process
- high variability during printing

“4D” Printing

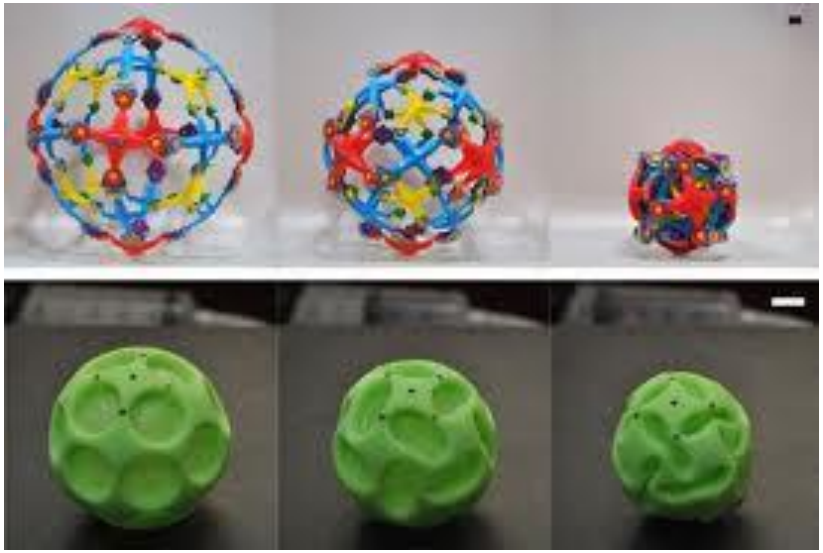
Controlling stiffness

[Schumacher et al]

“4D” Printing

Controlling stiffness

- one example of a **metamaterial**: emulating the behavior of other materials by altering fine-scale geometry



“4D” Printing

Controlling deformations

[Perez et al]

Beyond 3D Printing

Texture Mapping Real-World Objects with Hydrographics

Daniele Panozzo[1] Olga Diamanti[1] Sylvain Paris[2]

Marco Tarini[3,4] Evgeni Sorkine[1] Olga Sorkine-Hornung[1]

[1]ETH Zurich [2]Adobe [3]Università dell'Insubria [4]ISTI-CNR Pisa

ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

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Adobe

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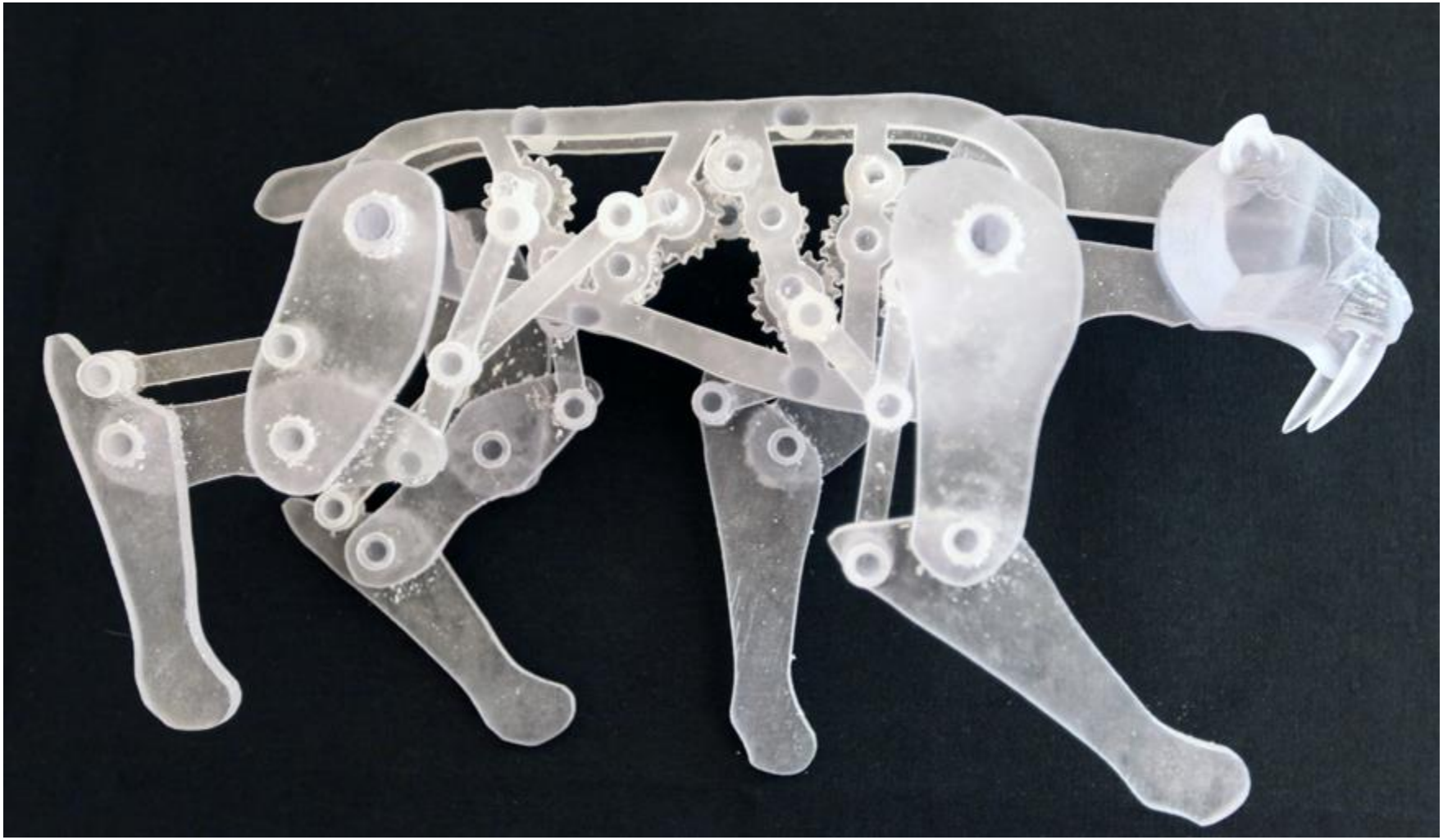
Beyond 3D Printing



Where To Go From Here

Graphics conferences:

- SIGGRAPH / SIGGRAPH Asia
- Symposium on Geometry Processing
- Symposium on Computer Animation
- Eurographics

Where To Go From Here

Closely allied fields:

- Computer vision (Grauman)
- Robotics (Stone, Niekum)
- Scientific Computing (Bajaj, Dhillon)

Advanced classes:

- Gaming capstone
- Physical simulation grad class

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    - **DANGER: there will be calculus**

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Undergrad/grad research