A Design For An Object To Be 3D Printed Should Be A Transformable Parametric Design

Session B, 11:00AM, July 25, 2023

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Annual NNCI
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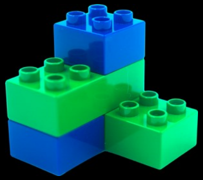
What is 3D Printing?

Subtractive Building:

“Every block of stone has a statue inside it and it is the task of the sculptor to discover it.”

- Michelangelo



Additive Building:

“The whole is greater than the sum of its parts.”

- Aristotle

Why Parametric Design?

Design for Manufacturability (DFM):
Design product so it is easy to manufacture, but different tools/materials have different constraints.

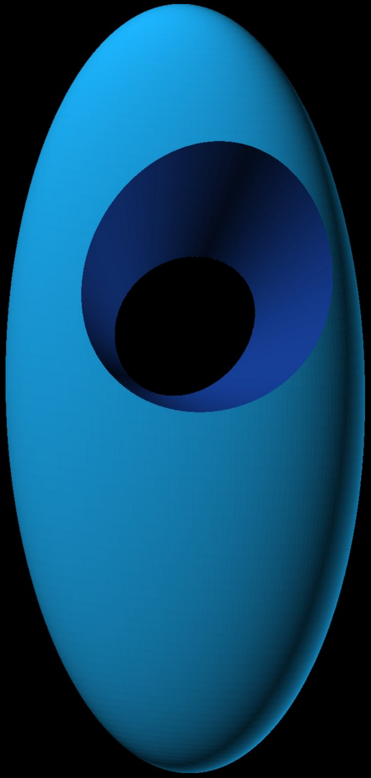
- Lego doesn’t easily do curves...
- Fused Deposition Modeling (FDM, FFF), Material Jetting (MJ), Drop On Demand (DOD) don’t easily do unsupported…
- Stereolithography (SLA, DLP, LCD), Selective Laser Sintering/Melting (SLS/SLM, EBM), Binder Jetting (BJ) don’t easily do cavities...

The Design Process

- **Conventional design for 3D printing**:
  1. Create 3D model by drafting in a CAD system
  2. Convert model to "portable" polygonal surface patches (STL)
  3. Slice STL into machine-specific G code X, Y, Z, E movements

- **A better design process for 3D printing**:
  1. Create a parametric design as a program
  2. Compile the design program + parameter values into a DFM-optimized machine-specific design
  3. Convert design into G code

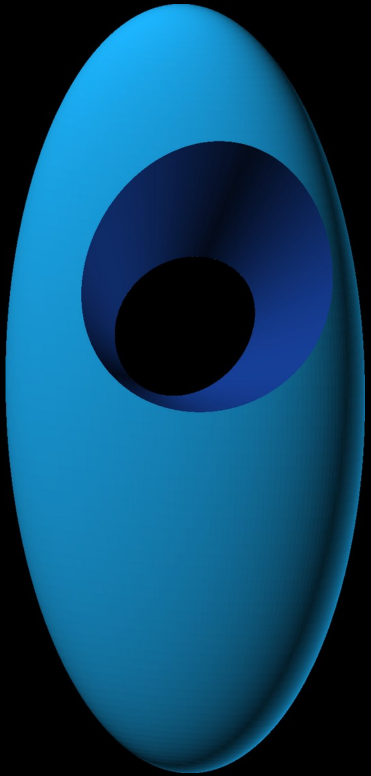
A Trivial OpenSCAD Example



OpenSCAD supports parametric program representations with variables, but intent, functionality, and constraints are not coded

```
difference() {
 scale([0.5, 1, 2])
 sphere(d=100);
 translate([0, 0, 20])
 rotate([30, -115, 0])
 cylinder(d1=80, d2=20,
          h=100, center=true);
}
```

How About A Base Fitting This?



- Make this a module with parameters:

```
module statue( … ) { … }
```

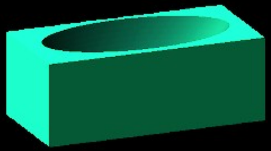
- Make a base module too
- Just difference ‘em to fit the base:

```
difference() { base(); statue(); }
```

We need a printer-dependent tolerance between them to get a good fit…

Parametric OpenSCAD

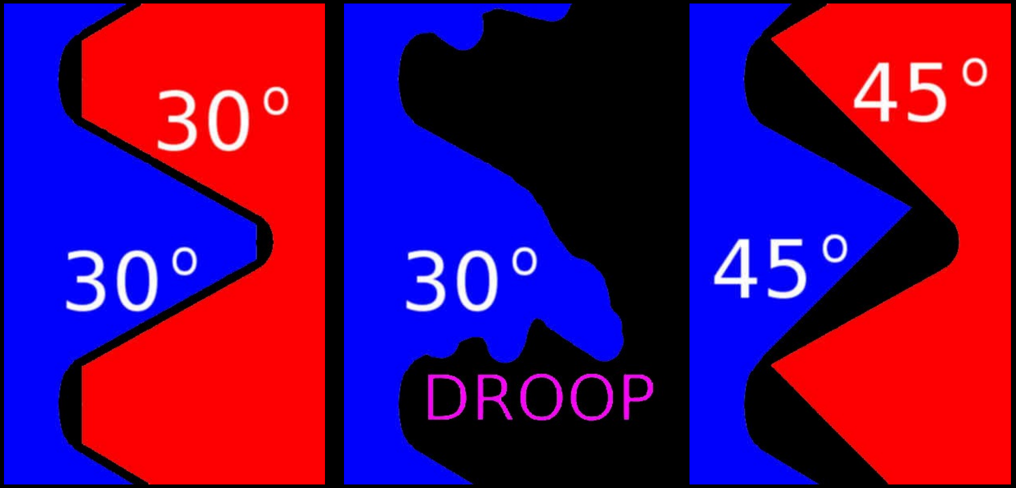
```
module tol(xt=defxt, yt=defyt, zt=defzt) {
 for(c=[0:1:$children-1]) minkowski() {
  children(c); scale([xt, yt, zt]) cylinder();
} }
```



```
difference() {base(80); tol() statue(80);}
difference() {base(); tol() statue();}
difference() {base(); tol(yt=2) statue();}
```

A Manufacturability Example

- The Unified Thread Standard (UTS) specifies a **30º angle** for screw threads
- Can we print that without **droop**?
- Replace **30º angle** with a printable one:
- **45º is safe**
- Could allow for droop



Implementing DFM Adjustments

- Manually edit all your design elements
- Use a **parts library** that exposes parameters
- Use **optimizing compiler technology**
- Use AI language models…
  GPT (Generative Pre-training Transformer)
- Use *fitness-based* AI optimization methods…
  GA / GP (Genetic Algorithm / Programming)

Compiler & Language Technology

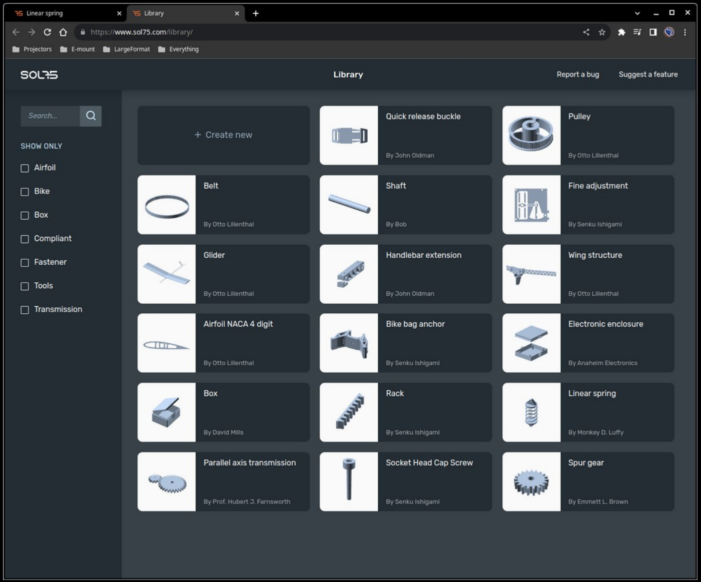
- Optimizing compiler technology:
  - Analysis creates *intermediate representation*
  - Correctness-preserving transformations replace matched patterns with better implementations

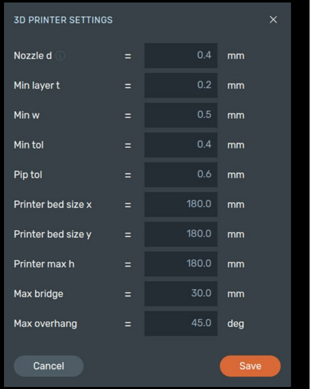
- GPT (Generative Pre-training Transformer):
  - ***Might*** recognize constructs, DFM violations
  - Create ***potential*** design elements
  - Coding, like `https://github.com/AntonOsika/gpt-engineer`

Fitness-Based AI Optimization

- Sol75, 2021

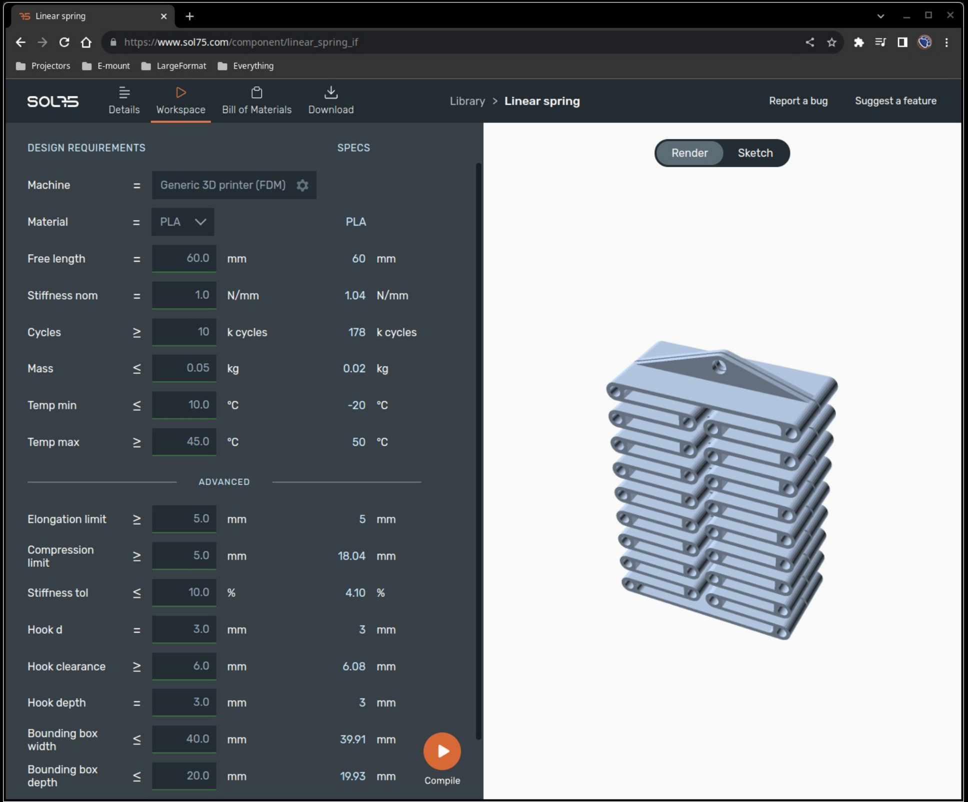
  `https://www.sol75.com`





3D PRINTER SETTINGS

Nozzle d	=	0.4	mm
Min layer t	=	0.2	mm
Min w	=	0.5	mm
Min tol	=	0.4	mm
Pip tol	=	0.6	mm
Printer bed size x	=	180.0	mm
Printer bed size y	=	180.0	mm
Printer max h	=	180.0	mm
Max bridge	=	30.0	mm
Max overhang	=	45.0	deg



DESIGN REQUIREMENTS				SPECS	
Machine	=	Generic 3D printer (FDM)			
Material	=	PLA		PLA	
Free length	=	60.0	mm	60	mm
Stiffness nom	=	1.0	N/mm	1.04	N/mm
Cycles	≥	10	k cycles	178	k cycles
Mass	≤	0.05	kg	0.02	kg
Temp min	≤	10.0	°C	-20	°C
Temp max	≥	45.0	°C	50	°C
ADVANCED					
Elongation limit	≥	5.0	mm	5	mm
Compression limit	≥	5.0	mm	18.04	mm
Stiffness tol	≤	10.0	%	4.10	%
Hook d	=	3.0	mm	3	mm
Hook clearance	≥	6.0	mm	6.08	mm
Hook depth	=	3.0	mm	3	mm
Bounding box width	≤	40.0	mm	39.91	mm
Bounding box depth	≤	20.0	mm	19.93	mm

Built-Assembled Hinge Options

*Many hinge designs require a trapped pin, which usually implies an **unsupported span***

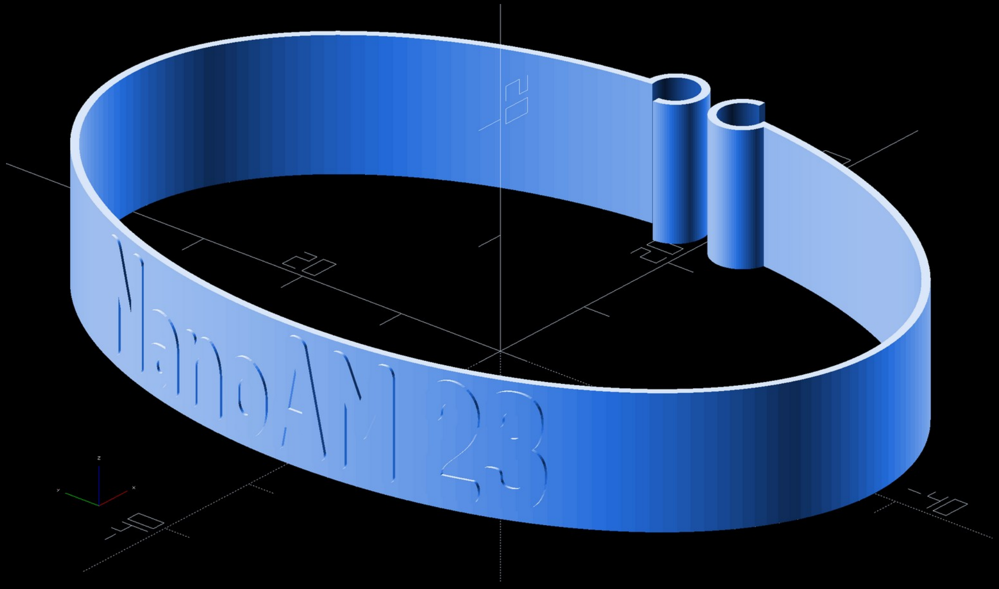
- Hope you’ll get a usable print anyway
- Use internal break-away/soluble supports
- Use a compliant/metamaterial mechanism
- Use a span-free hinge design

This type of choice can be automated!

Compliant Bracelet

*Take advantage of **material properties***

- FDM printed in PLA or silk PLA
- Compliant open/close
- Clasp fail (deforms): >25**lbs load**

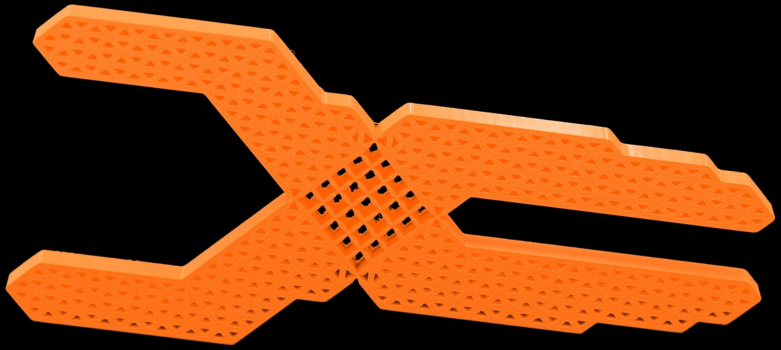


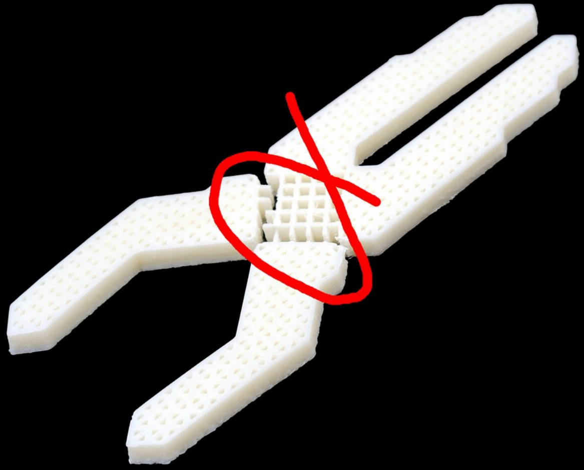
Not very compliant...

Compliant/Metamaterial Pliers

We need a hinge, a spring, and a rigid jaw

- Prof. Baudisch, Hasso-Platner Institute, 2016
  `https://hpi.de/baudisch/projects/metamaterial-mechanisms.html`



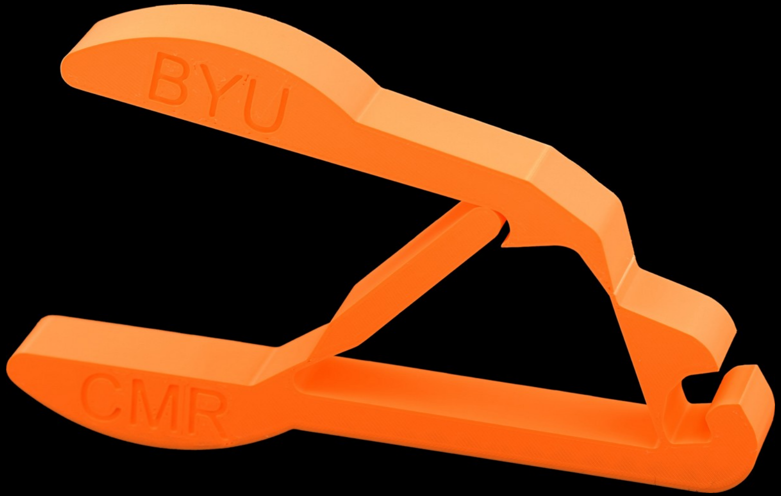


Compliant/Metamaterial Pliers

We need a hinge, a spring, and a rigid jaw

- Compliant Mechanisms Research Group (CMR), Brigham Young University (BYU), 2019

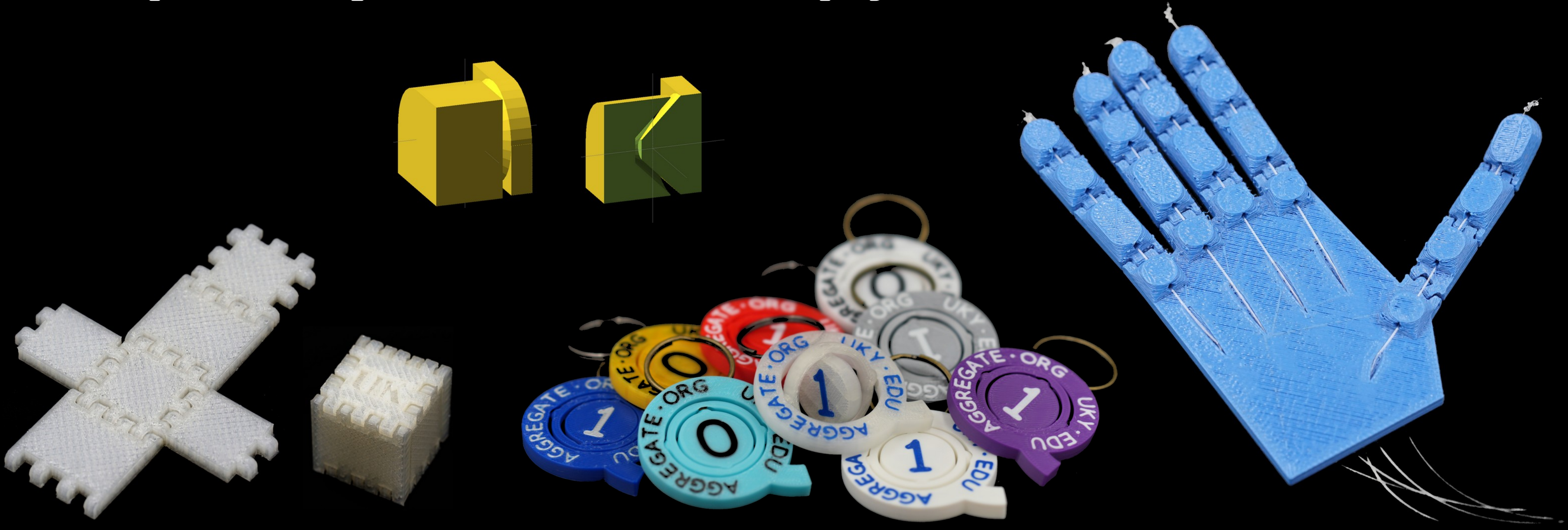
`https://compliantmechanisms.byu.edu/maker-resources`



Built-Assembled Span-Free Hinge

- It started with my HingeBox in 2013:

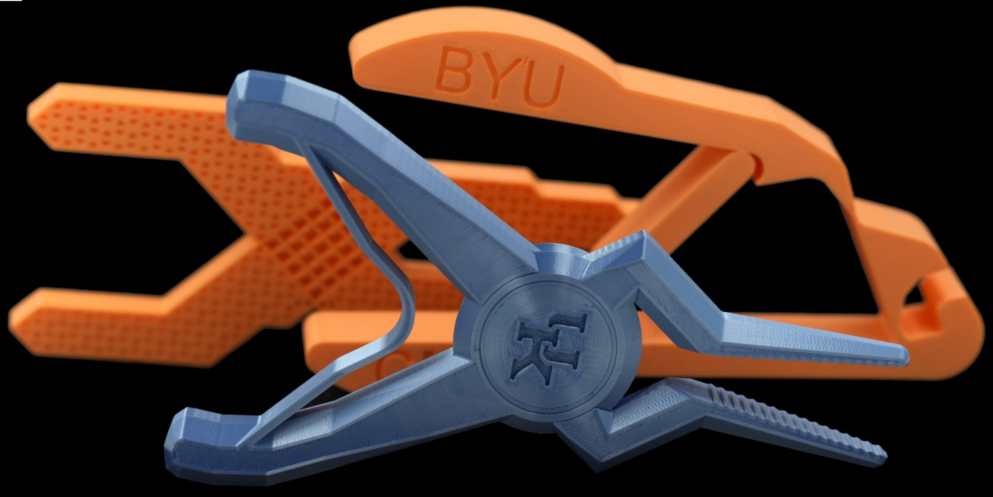
  `https://www.thingiverse.com/thing:120179`
  `https://www.youtube.com/watch?v=PpIg92-3MT0`



Compliant/Metamaterial Pliers

We need a hinge, a spring, and a rigid jaw

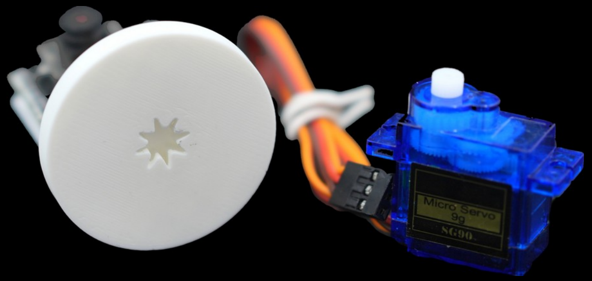
- Aggregate.Org, University of Kentucky, 2016
  `http://aggregate.org/MAKE`



Mini/Micro Servo Horn

Servo horns have to fit a gear that, especially on mini/micro servos, has ***unprintably fine teeth***

- Simply print a mating hole
  with fewer teeth or contact points
  (Paul Dietz, 2021; me, 2022):



Conclusion (are we there yet? ♥)

- Designs for 3D printing (any making!) should:
  - Be parametric, e.g., like **OpenSCAD** ♥
  - Build a library of DFM problem solutions ♥
  - Include intent, functionality, and constraints ♥
  - Use tools to automate DFM ♥
  - Use AI methods to optimize parameters ♥
- Want more info? See: Aggregate.Org

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