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On-Demand Digital Fabrication and Computational Design Method for E-Textile

Prime contractor: *Palo Alto Research Center, Inc. (PARC);*

Technical POC: Qian Ye, Giovanna Bucci, Anurag Bhattacharyya, Morad Behandish

Introduction & Motivation

Communication

Sensors

Actuator

Data Processing /storage

Power

Integration ?

1. **Fabrication: Textiles and electronic components**
2. **Design (an automated design approach):**
   - **Energy level**
     - **Self-powered e-textile**
   - **Multi-scale and multi-material**

Fabrication and Design are **interdependent**:
Fabrication constraints the design
Design enables fabrication

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1. Fabrication: Development of Fabrication Technologies for E-textiles

Belt-in

- Ease of implementation
- Accessories with fewer consideration of stretchability

Adhere/Glue

- Flexible and Stretchable
- Weak Bonding

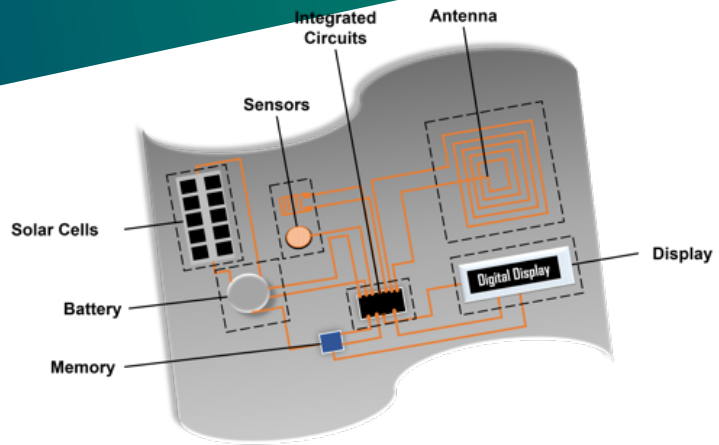
Sew-in

- Interlocking network of threads
- Large deformation
- Fabrication

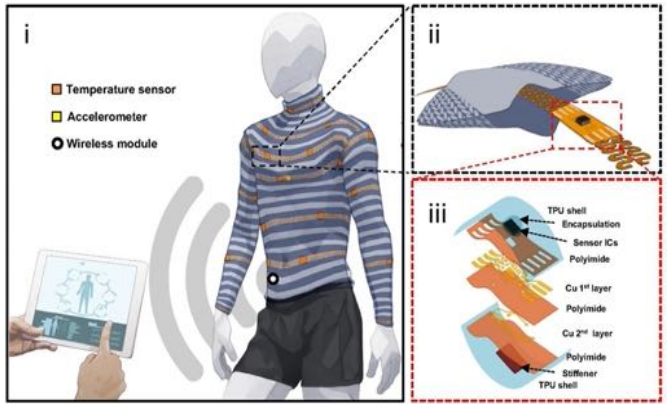
What's ongoing and what's next??

Integration level of E-textiles

A wearable Electronic heating device



A hybrid flexible electronics



Electronic devices embedded into knitted fabric
(Wicaksono et al. 2020)

- Fully **compatible the garment industry** (weaving, knitting, etc.)
- **Adapt the pros of fabric**:
  - Soft, saft, conformal to body shape, washable…
- **Scalable**

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1. Development of Fabrication Technologies for E-textiles

What's Next: Digital Fabrication Technologies e.g., conformal weaving

circuit

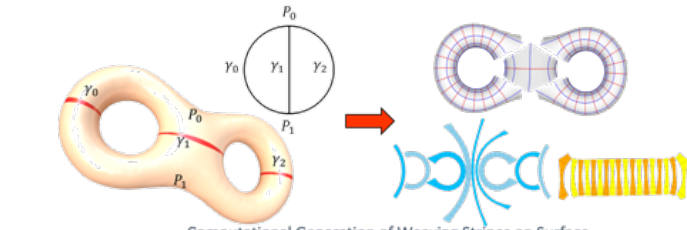
outline

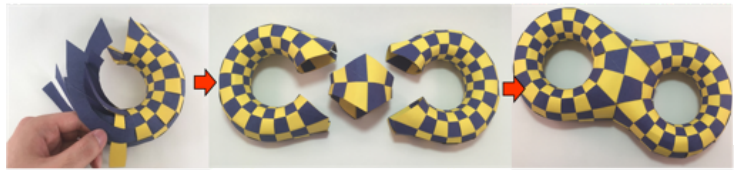
stars/LED

A method to design and weave a conformal flexible electronics on surface

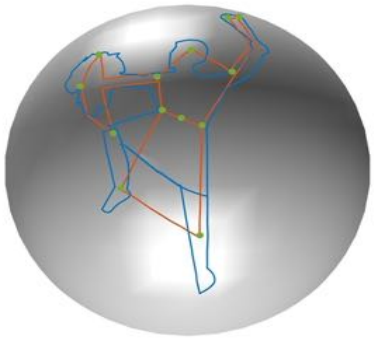
Manufacturing:

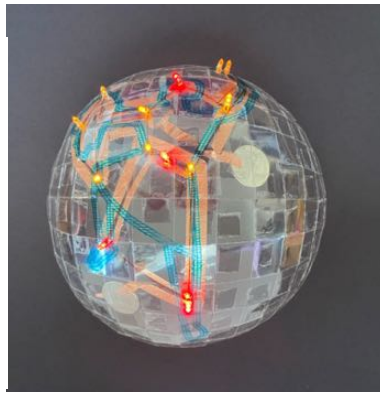
- **2D-printable electronics**: more reliable, efficient, and economical.
- Surface **shaped directly** during weaving: no stretching, bending only





(Yang Guo, Qian Ye et.al, CMAME 2020)

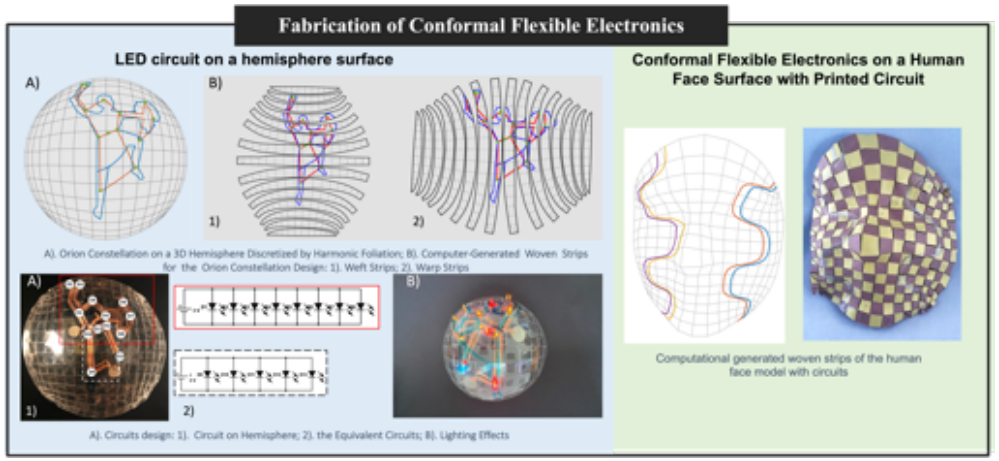




(Qian Ye et.al, IDETC 2021)

Method:

- Threads: dense **without self-intersection**
- **Automatic pipeline** suits for surfaces of various topologies



What you see is what you weave

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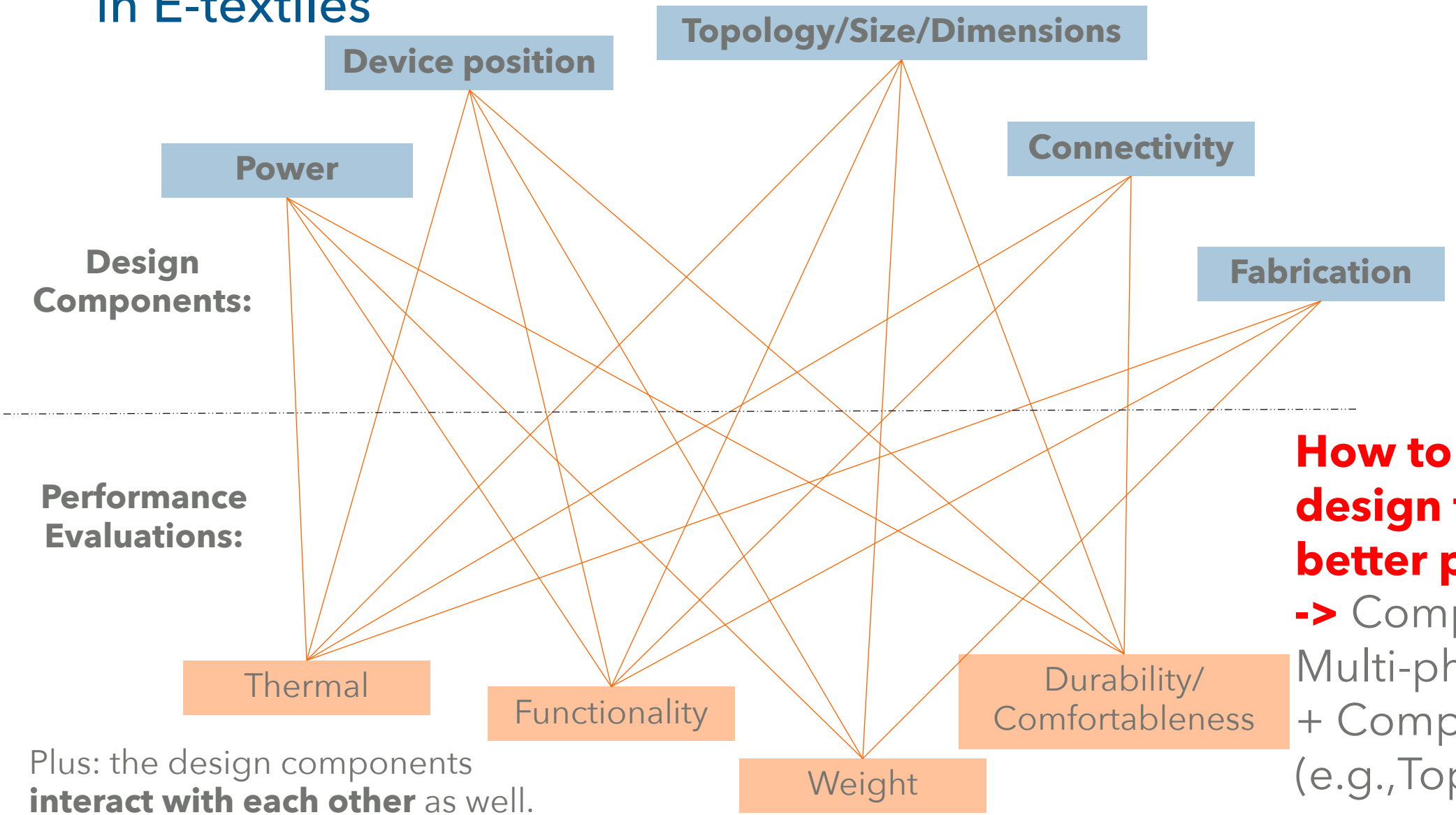
The interconnection between design problems and performance in E-textiles



Plus: the design components **interact with each other** as well.

How to intelligently design to achieve better performance?

-> Computational Tools: Multi-physics simulation + Computational design (e.g., TopOpt + AI)

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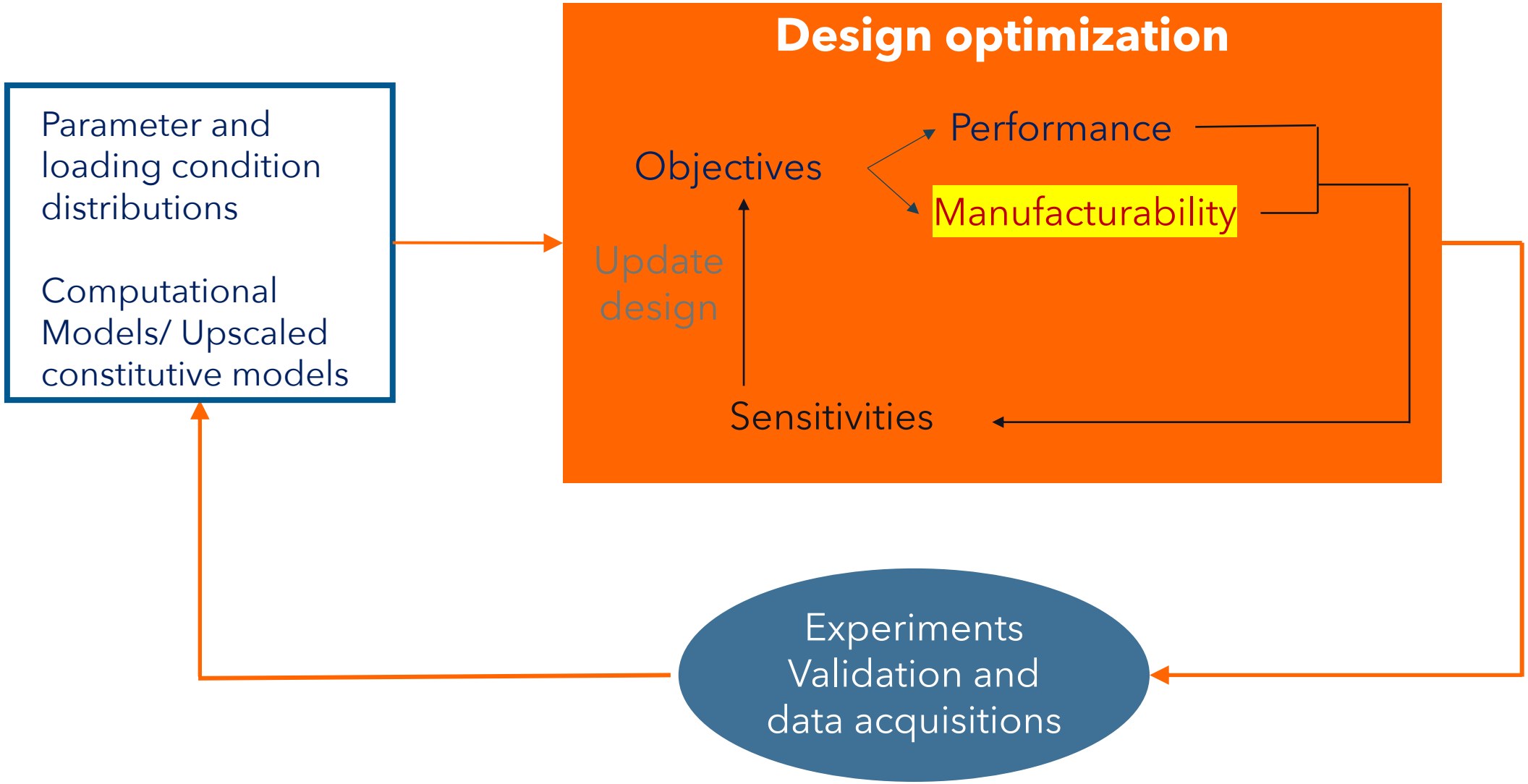
Learning loop for robust-automated design



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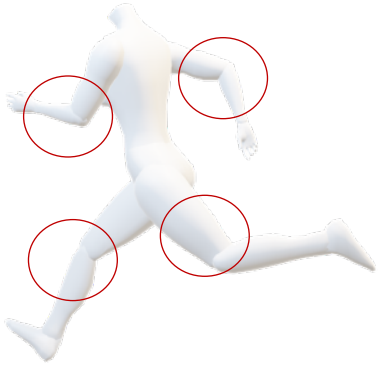
2. Design Problem 1: Improve the Integration Level of Energy Consumption
Design a Self-powered E-textile system

Energy Harvesting
from body movement

- **Flexible Piezoelectric Nanogenerators (PENGs)**
- **Flexible Triboelectric Nanogenerators (TENGs)**

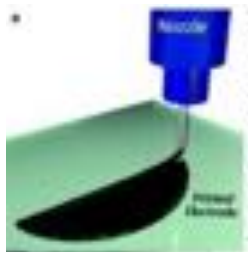


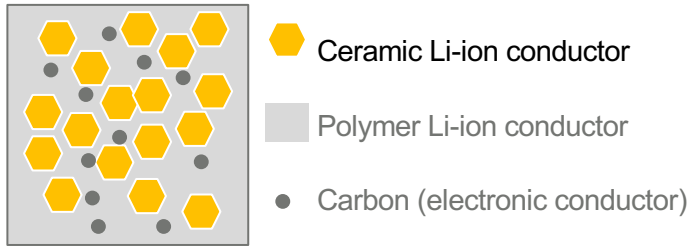
Current challenges:
1. Understand the multi-physics problem
2. Automated design

Design considerations:
- Manufacturing constraint: e.g., ability to be printed
- Flexible

Flexible Battery

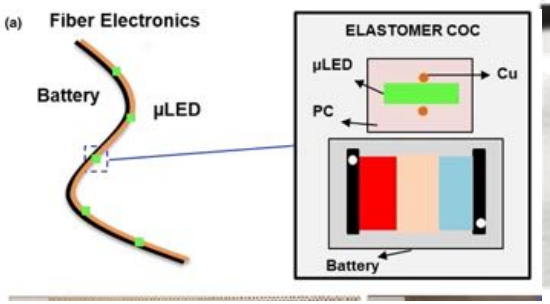
- **Printed battery**

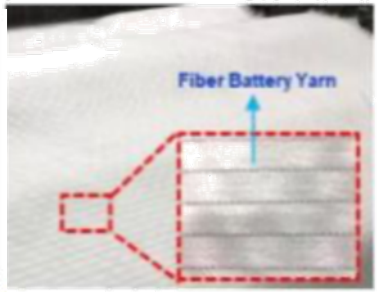




Ryan R.Kohlmeyer et al. https://pubs.rsc.org/en/content/articlelanding/2016/TA/C6TA07610F

- **Rechargeable fiber**





Tural Khudiyev et al. https://doi.org/10.1016/j.mattod.2021.11.020

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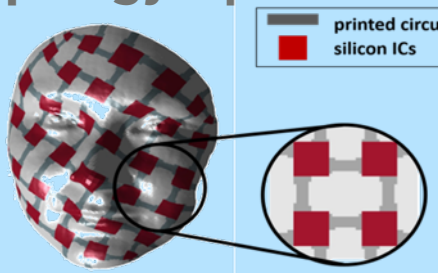
3. Design Problem 2: Improve the Integration Level of Multi-material and Multi-scale

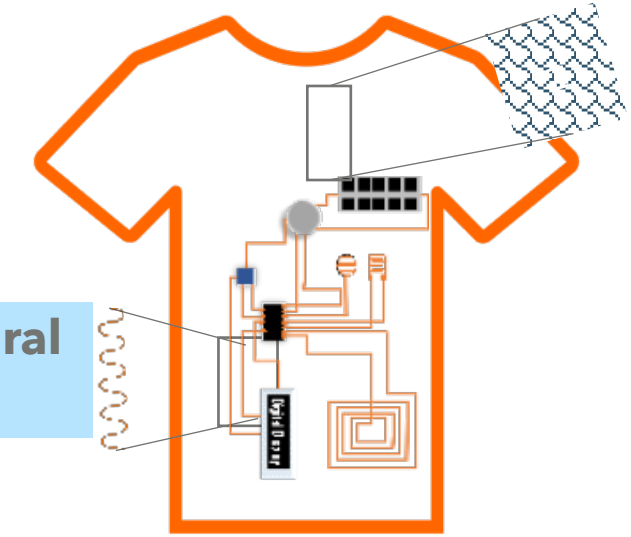
- Challenges and limitations: reliability under large deformation, fabrication cost
- Opportunity: e.g., **Topology Optimization**



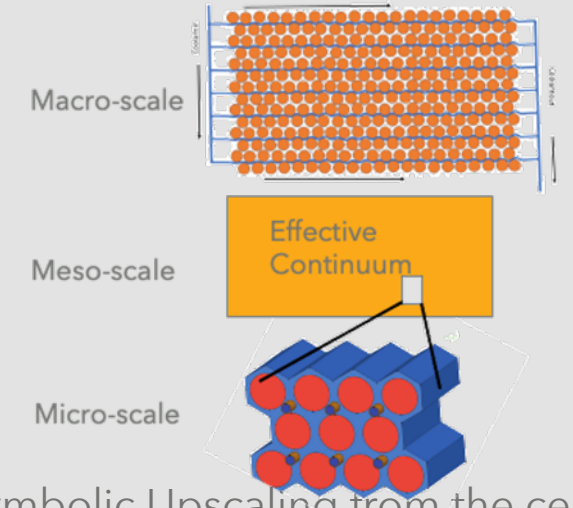
Schematic of optimized flexible electronics design on a human face surface

- **Rigorous homogenization:**
  - upscale nonlinear equations with guarantees

Structural Design



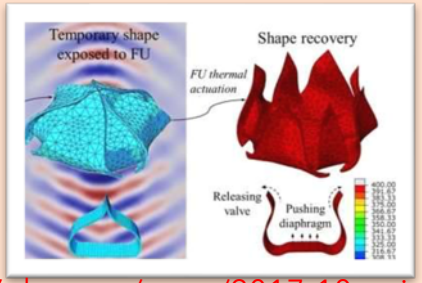
E-textile: a multi-material and multi-scale



A Symbolic Upscaling from the cell-scale to the battery pack-scale (DARPA-CompMods)

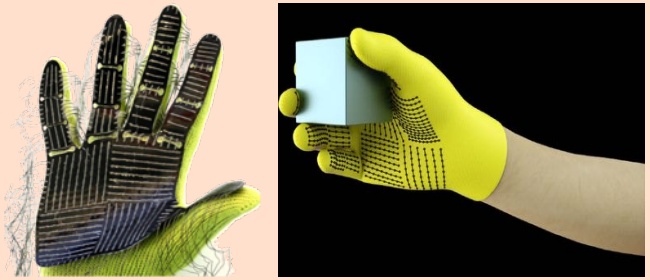
Textile Design

- Challenges: cycling stability, nano-cracks, wrinkling due to the Poisson effect
- Opportunities:
  - **Meta-material design**:
  - **Self sensing/active/ resilient**: Active material



https://phys.org/news/2017-10-unique-approach-smart-drug-delivery.html

- **Interaction with the environment** (Haptics)



"Scalable Tactile Glove" (STAG). (MIT, 2019) by Subramanian Sundaram, et al.

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THANK YOU

Qian Ye

qiaye@parc.com

PARC, a Xerox Company
3333 Coyote Hill Road
Palo Alto, CA 94304

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