Generative AI Models
ECE 598 LV – Lecture 22

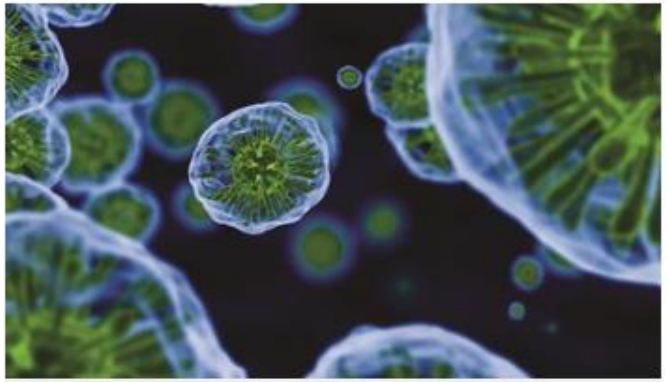
Lav R. Varshney

12 April 2022

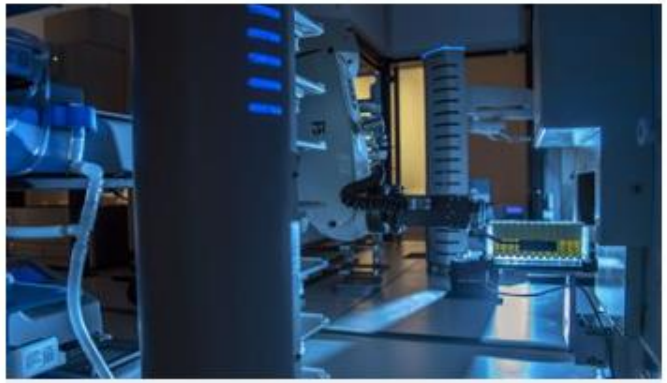
- Generative and creative AI models for engineering and industrial design

Aerospace Engineering

Agricultural and Biological Engineering



Bioengineering

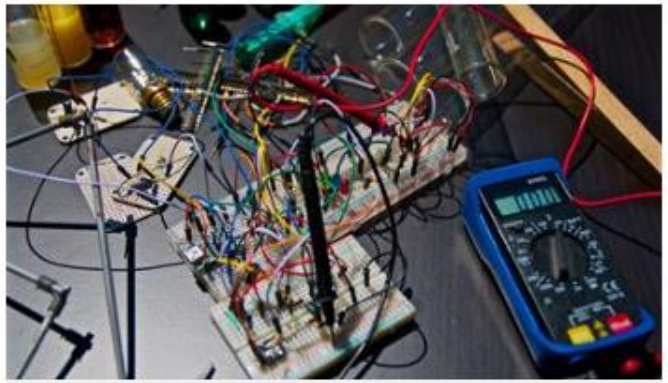


Chemical Engineering

Civil Engineering

Computer Engineering

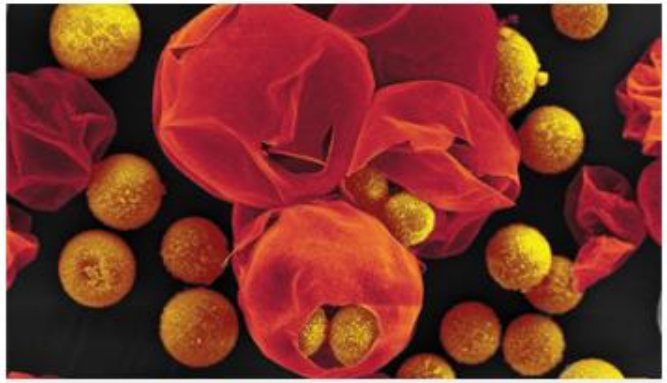
Computer Science



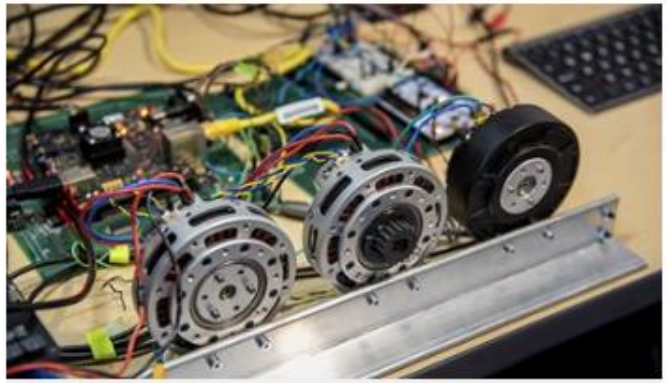
Electrical Engineering

Engineering Mechanics

Industrial Engineering

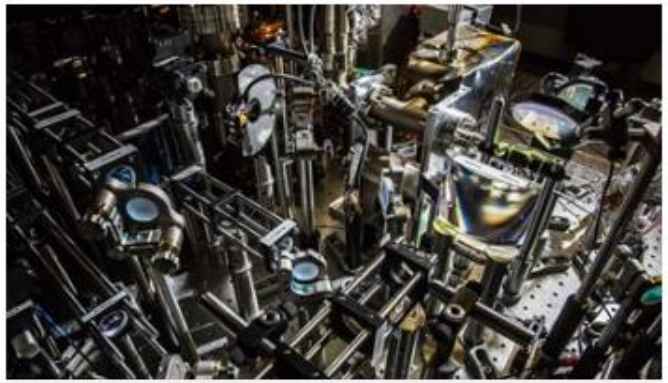


Materials Science and Engineering

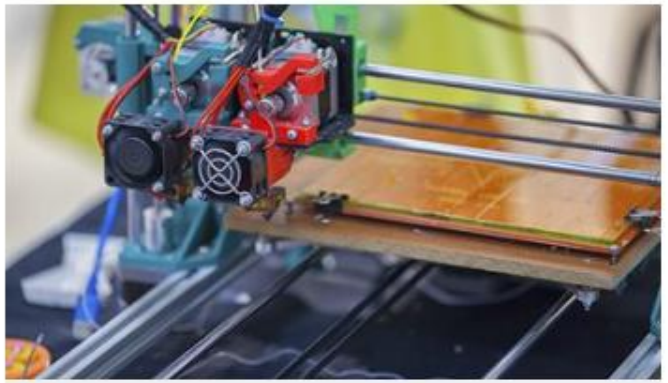


Mechanical Engineering

Nuclear, Plasma and Radiological Engineering



Physics



Systems Engineering and Design

B.S. DUAL DEGREE OPTION

Innovation, Leadership & Engineering Entrepreneurship (ILEE)

The B.S. dual degree in Innovation, Leadership and Engineering Entrepreneurship (ILEE) program is intended for engineering students to better understand the

Engineering Science is Dominant

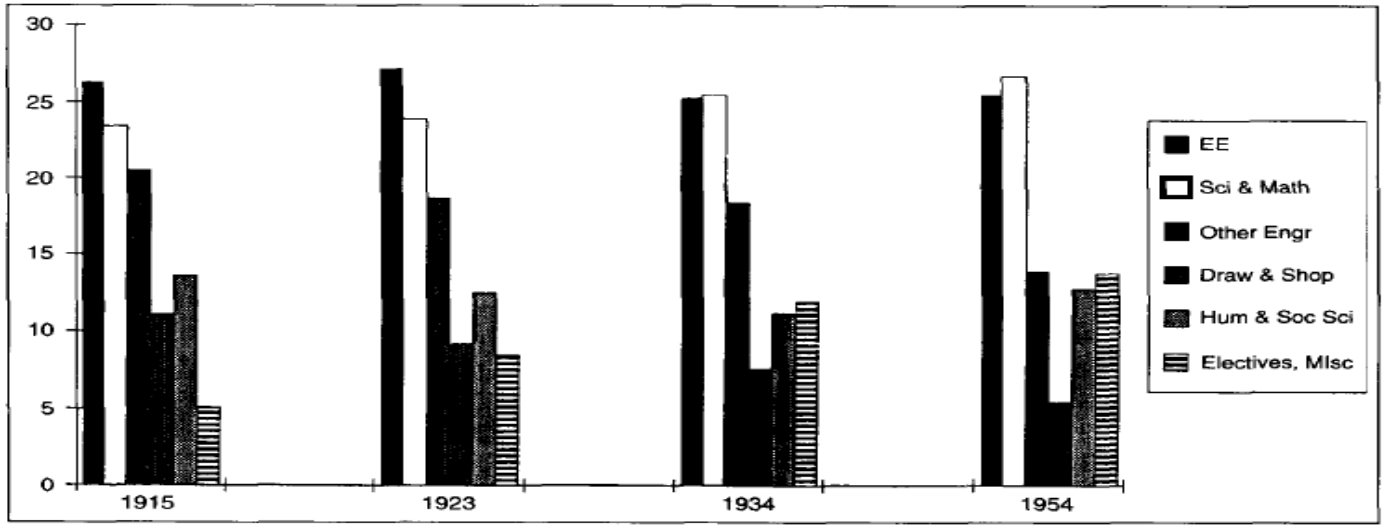


Fig. 1. U.S. electrical engineering curricula. percentages of subjects [6]-[8], [38].

[R. R. Kline, "World War II: A Watershed in Electrical Engineering Education", *IEEE Technol. Soc. Mag.*, 1994.]

- In EE curricula from 1915 to 1954, time devoted to science/mathematics gradually increased, whereas percentage of other engineering, drawing, and shopwork dropped.
- The exponential growth in graduate education after WWII eventually impacted undergraduate education. Graduate courses were pushed down into required junior courses to make way for graduate courses at the frontiers of research.
- In the transformation, concrete experiences and practice-based knowledge were often lost.

To design complicated things requires knowledge of the physical world; to serve people properly requires knowledge about the social world

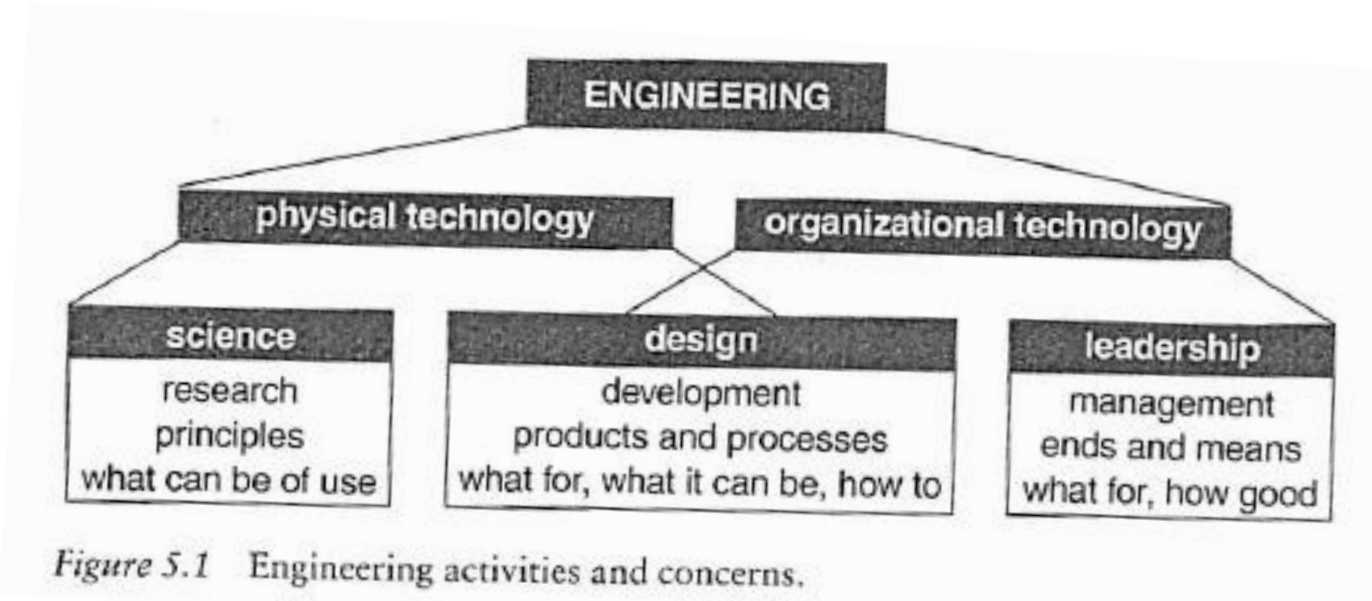
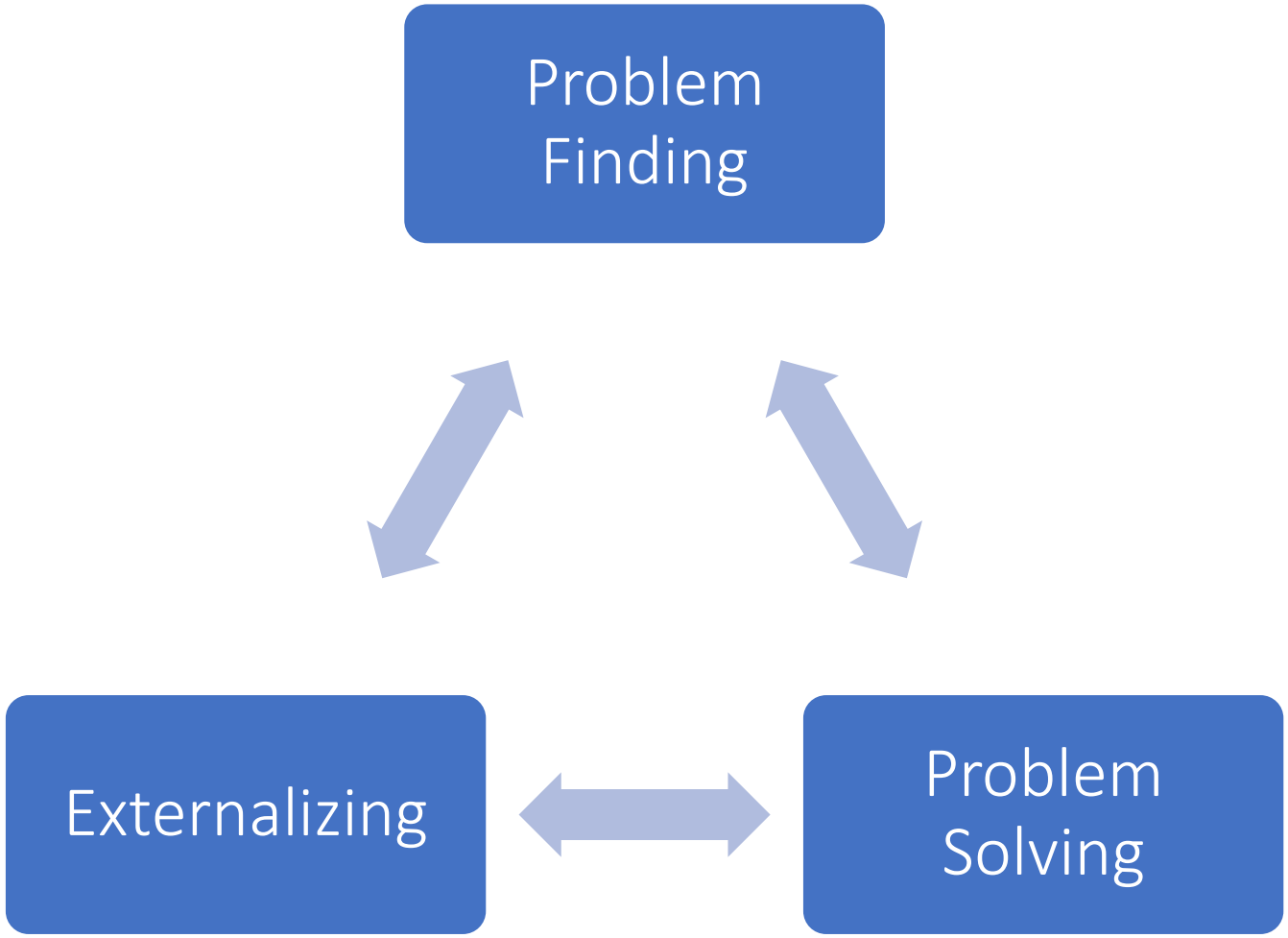


Figure 5.1 Engineering activities and concerns.

[S. Y. Auyang, *Engineering—An Endless Frontier*, Harvard University Press, 2004.]

The dual physical and human dimensions and triple aspects of science, design, and leadership provide a framework for thinking about engineering


Problem Finding
Externalizing
Problem Solving

In Engineering Science Curricula, which Engineering Competencies may be Neglected?

[N. Duval-Couetil, J. Wheadon, E. Kisenwether, and J. Tranquillo, " Entrepreneurship and ABET Accreditation: How and Where Does it Fit?," 2013]

Innovation, Leadership, and Engineering Entrepreneurship

- New degree programs like the BS in ILEE degree program is intended for engineering students to better understand the innovative processes involved in identifying problems and creating, developing, and leading efforts to provide engineering solutions.
- The curriculum is based on a sound disciplinary engineering technical core with additional aspects of problem identification and innovation, and complex multidisciplinary engineering project management and leadership.

Good industrial design can accelerate adoption of revolutionary technology-driven products and yield behavior change

smart home

consumer electronics

Take advantage of novel design to drive human attention to sustainable technologies

[Bern, Switzerland]

Use artificial intelligence to accelerate the design process [deep learning, computational creativity]

[Pinar Yanardag, 2019]

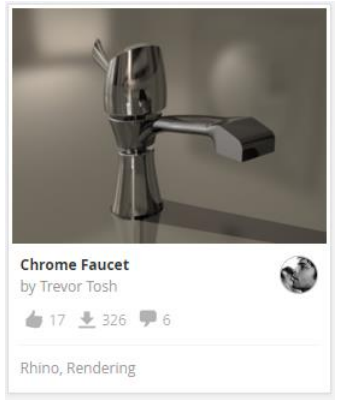
Use artificial intelligence to accelerate the design process [deep learning, computational creativity]

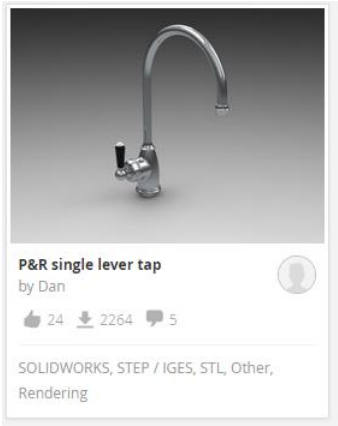
AI-GENERATED DESIGN

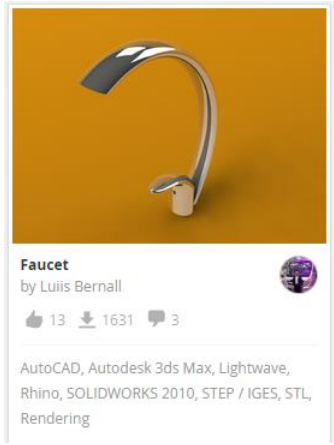
MADE IN REAL LIFE

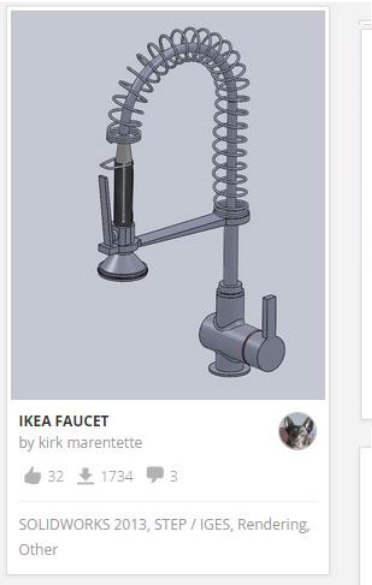
[Pinar Yanardag, 2019]

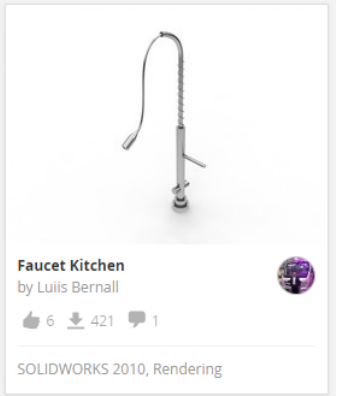
Use artificial intelligence to accelerate the design process [deep learning, computational creativity]

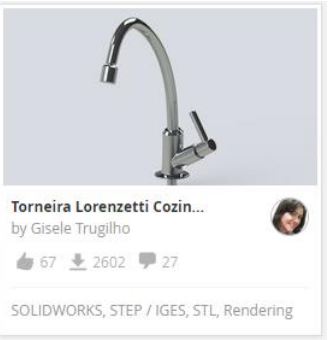












[https://grabcad.com]

3D CAD corpus for training the artificial intelligence algorithm

Computational creativity may seem like a stunt

SCIENCE | food | wired magazine

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Digital Gastronomy

WHEN AN IBM ALGORITHM COOKS, THINGS GET COMPLICATED—AND TASTY.

Prop styling: Laurie Raab | Justin Fantl

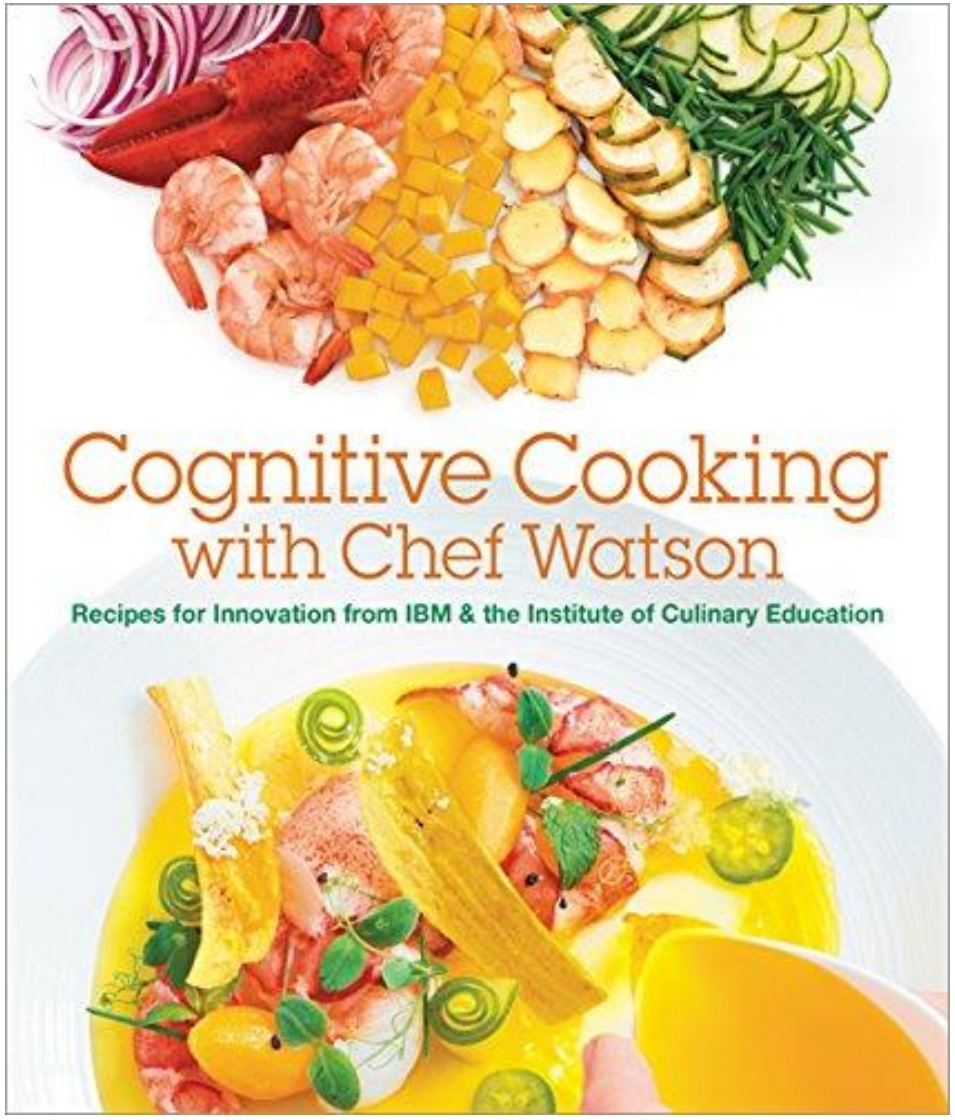
IBM's AI-like computer systems aren't limited to Watson, the *Jeopardy*-winning supercomputer that schooled Ken Jennings on national television. In fact, IBM researchers foresee a not-so-distant future when algorithms will be a replacement for inefficient customer service models, a diagnostic tool for doctors, and believe it or not, chefs.

Researcher Lav Varshney has already built an algorithm that creates recipes from parameters like cuisine type, dietary restrictions, and course. The system determines optimal mixtures based on three things: tens of thousands of recipes taken from sources like the Institute of Culinary Education or the Internet, a database of hedonic psychophysics (what humans like to eat), and food chemistry. Right now, the result is like a pre–Julia Child cookbook, providing chefs, who already know cooking basics, with suggestions for billions of ingredient combinations but no instructions.

To test its skill, we pitted IBM's algorithm against go-to-recipe resource Epicurious (owned by WIRED's parent company, Condé Nast). We searched the site for a Caribbean plantain dessert and found a tasty concoction with rum and coconut sauce. With the same parameters, IBM's computer generated a list of about 50 ingredients, including orange, papaya, and cayenne pepper, from which IBM researcher and professional chef Florian Pinel developed a mind-blowing Caymanian parfait. While the IBM dessert tasted better, it was also insanely elaborate, so we'll call it a draw.

—Allison P. Davis

[*Wired*, 1 Oct. 2013]

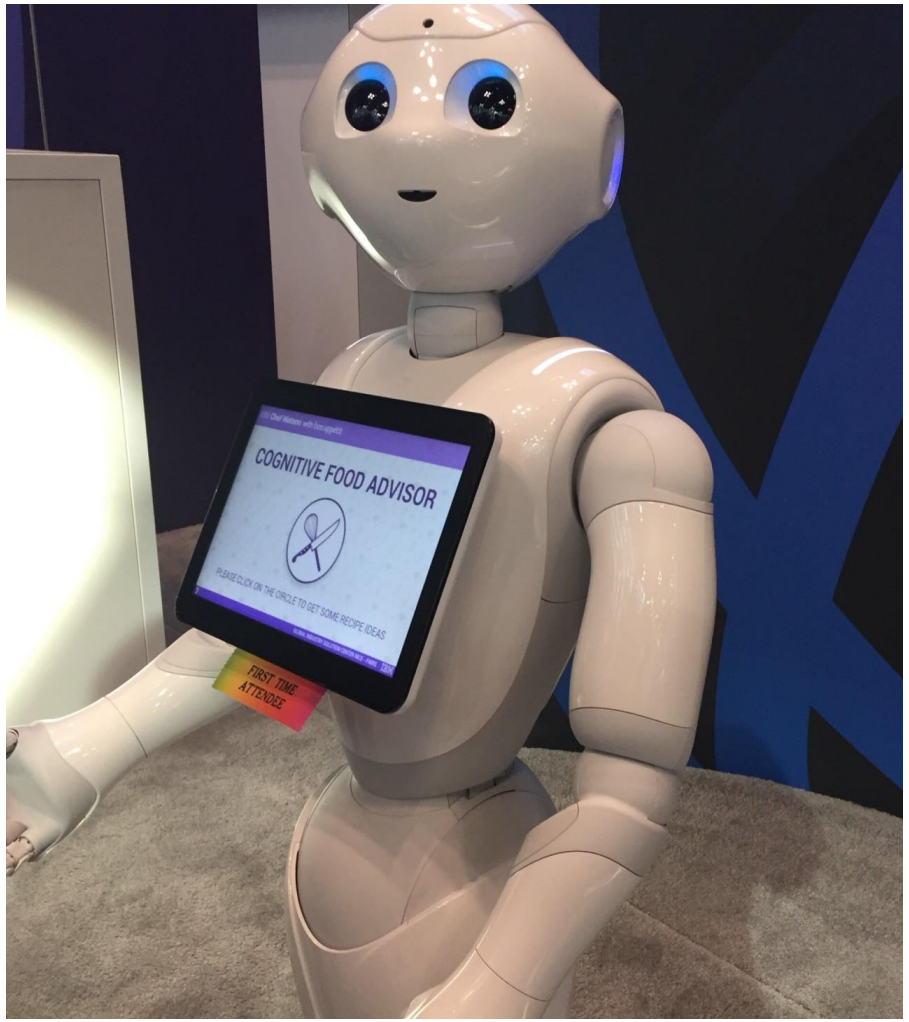


Computational creativity has been used in widescale practice

users as designers of custom products

internal design processes of large companies

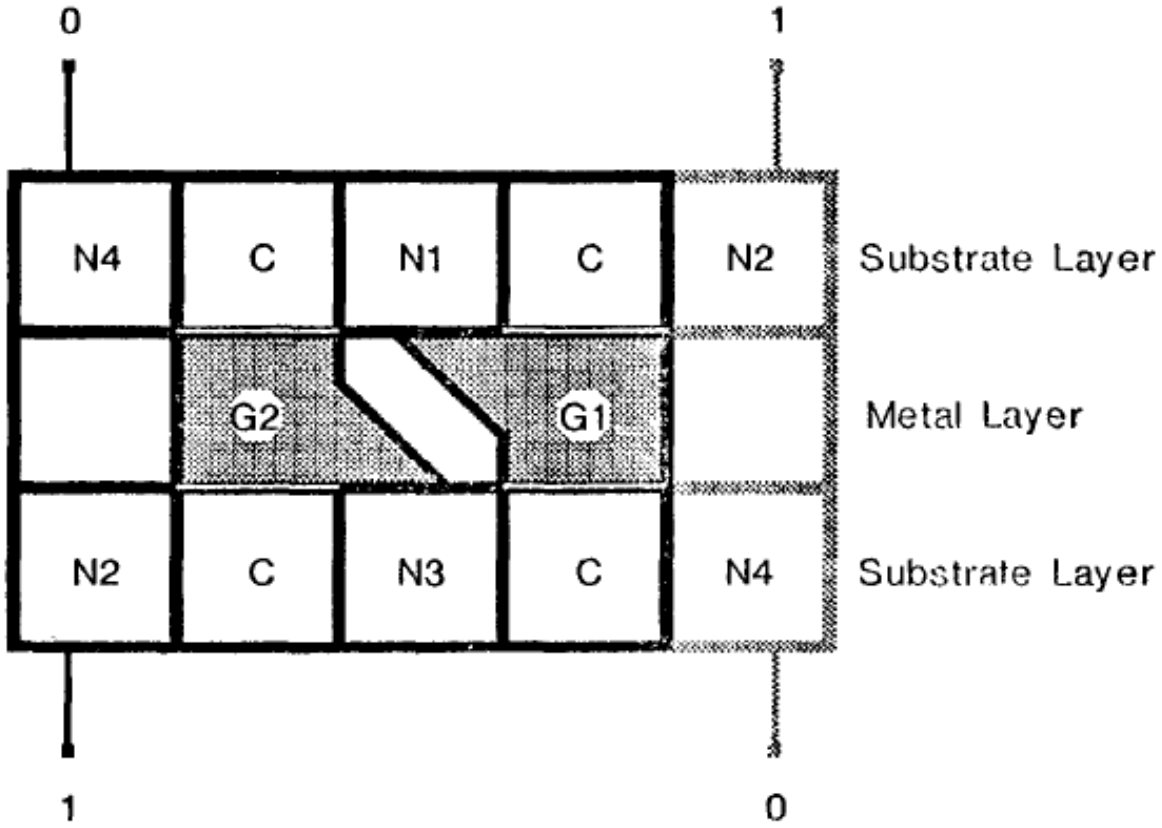
Augment human intelligence

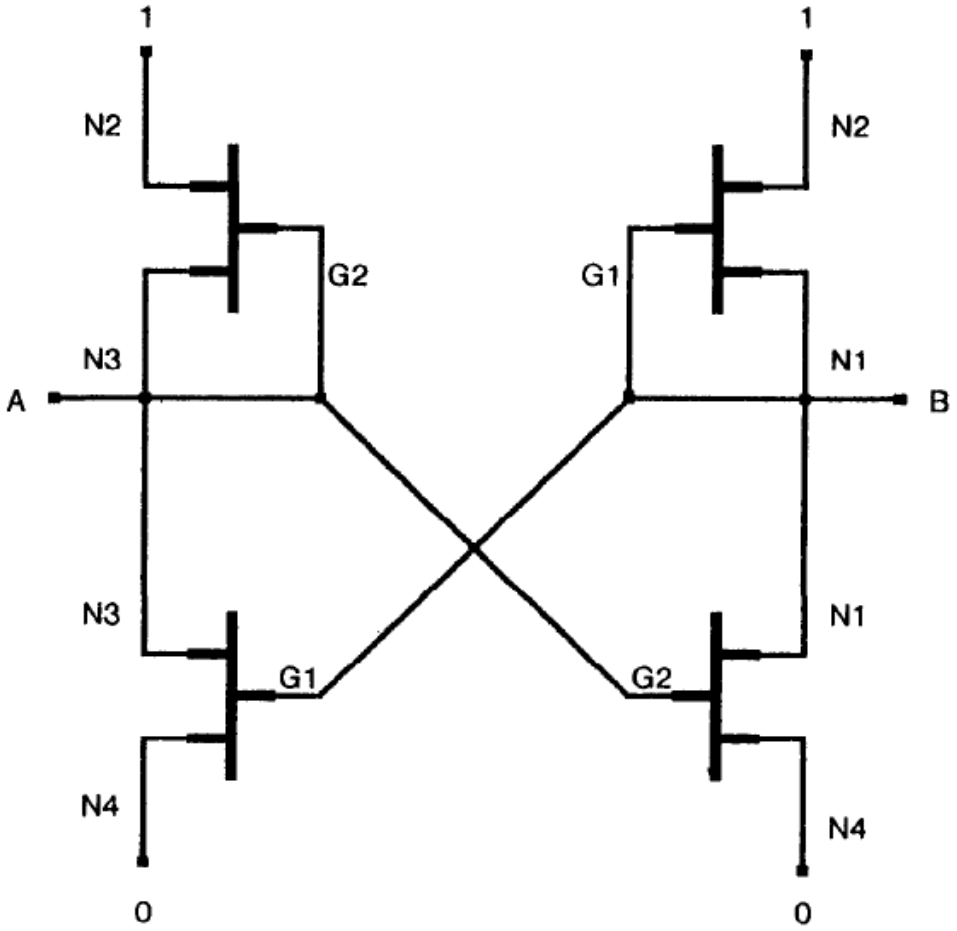


Note that this person does not exist: the photograph was created by a creative deep learning algorithm

[https://thispersondoesnotexist.com/]

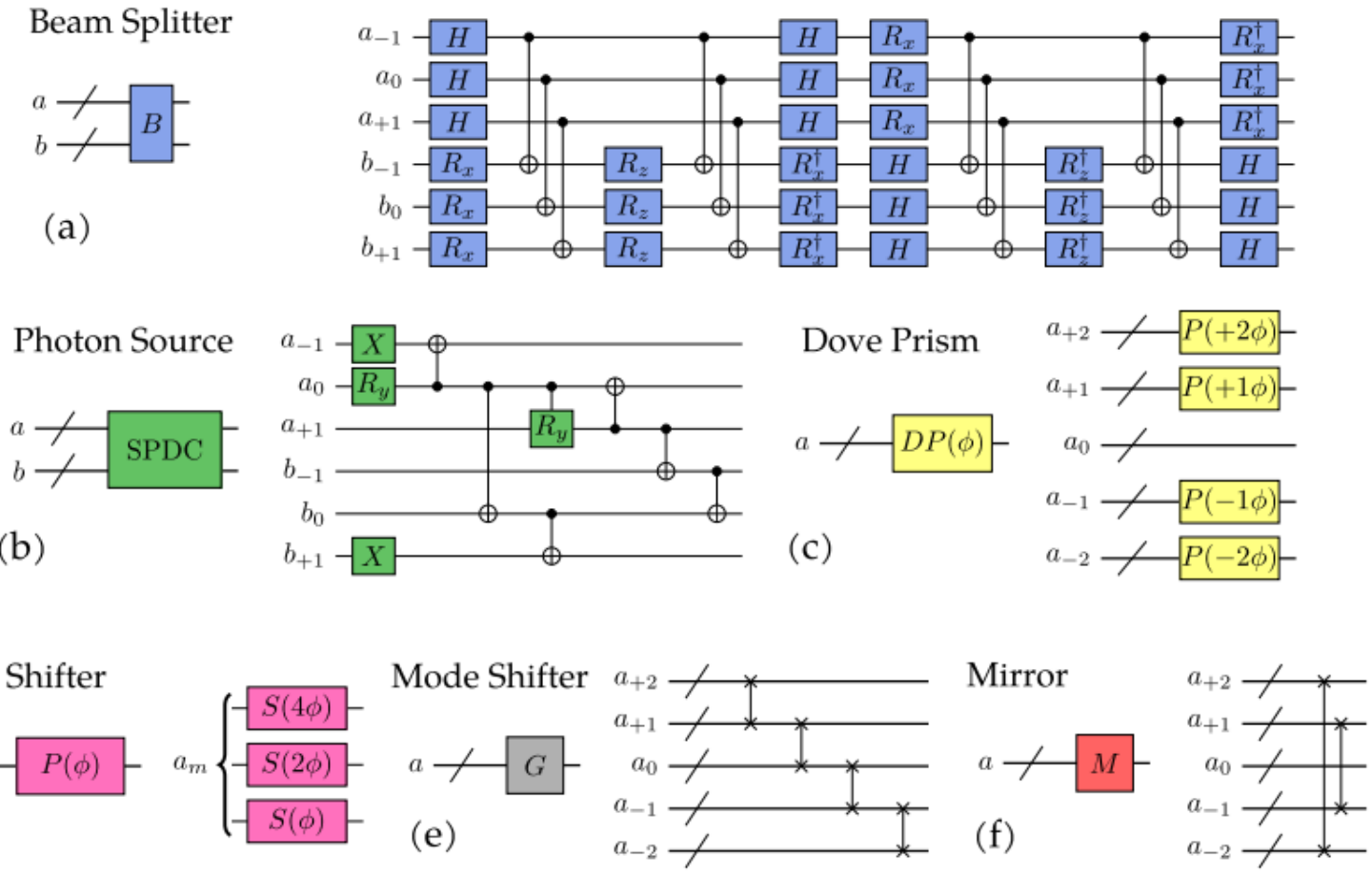
Circuits





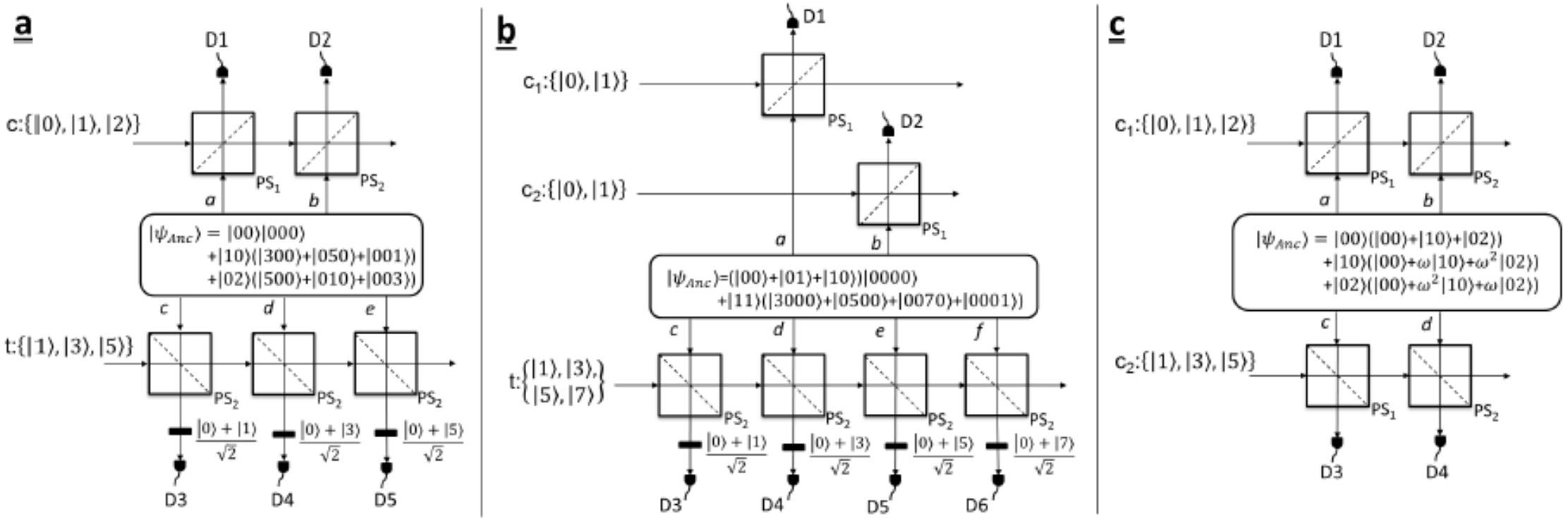
[D. B. Lenat, W. R. Sutherland, and J. Gibbons, “Heuristic Search for New Microcircuit Structures: An Application of Artificial Intelligence,” *AI Magazine*, Summer 1982.]

Quantum Optics Experiments and Computing Circuits



[Kottmann et al., 2021]

Quantum Optics Experiments and Computing Circuits



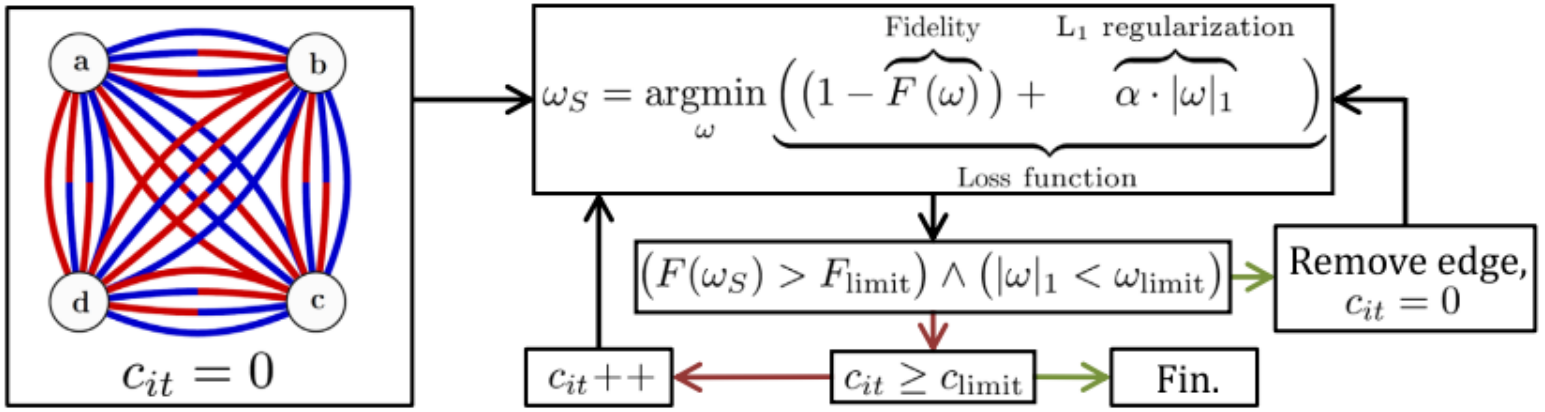
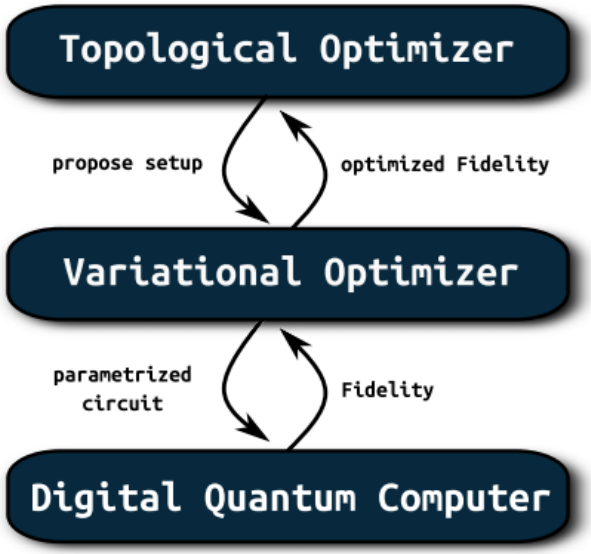


FIG. 2. Algorithm—THESEUS: The initial graph contains all possible edges between each vertex, leading to $|G| = d^2[n(n-1)/2]$ edges (with n vertices and d different edge colors), each of them having an independent complex weight $\omega_{v_1,v_2}^{m_1,m_2}$, where v_1 (v_2) stands for the first (second) vertex, and m_1 (m_2) stands for the color of the edge close to vertex v_1 (v_2).. The main step is a minimization of the loss function, which contains the quantum fidelity in terms of weights of the graph. Additionally, an L_1 regularization term controls the magnitude of the weights. If the weights identified by the optimization, ω_S, lead to fidelities larger than F_{limit}, and the magnitude of the weights is smaller than ω_{limit}, then one edge of the graph is removed, and the optimization continues with the smaller graph. On the other hand, if the criteria are not fulfilled, the same graph is optimized (with different starting conditions) until the discovery of a suitable solution or the number of iterations exceeds c_{limit}. The result of THESEUS is a weighted graph that leads to sufficiently large fidelities,



[Kottmann et al., 2021]
[Krenn et al., 2021]

BIKED: A Dataset for Computational Bicycle Design with Machine Learning Benchmarks

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Email: faez@mit.edu

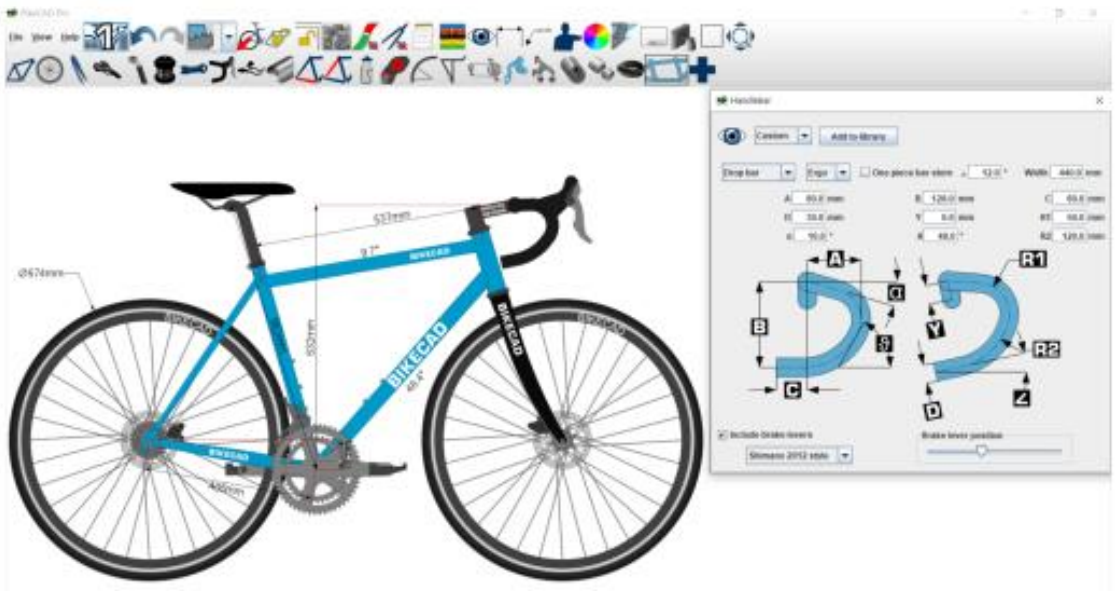
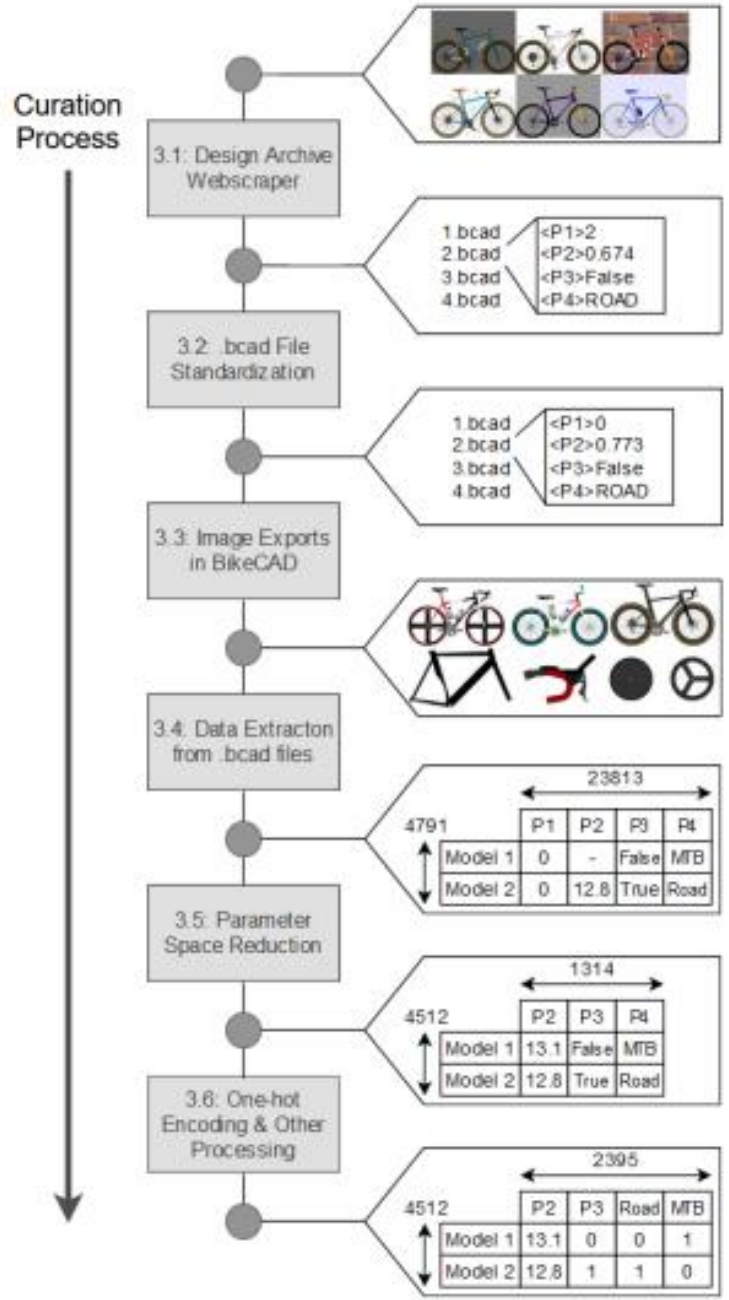
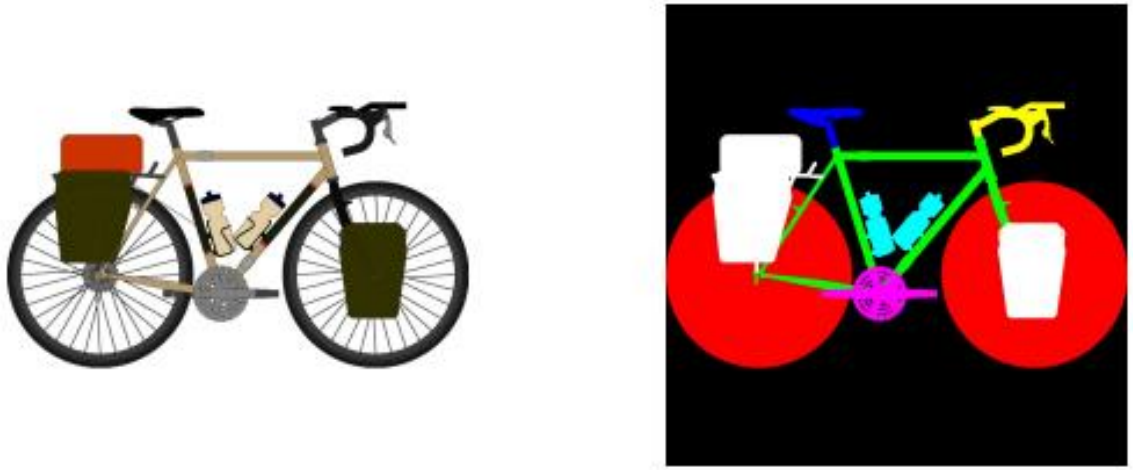


Fig. 1: Screenshot from BikeCAD software showing active model with some dimensional labels and an open menu.


Curation Process
3.1: Design Archive Webscraper
3.2: .bcad File Standardization
3.3: Image Exports in BikeCAD
3.4: Data Extracton from .bcad files
3.5: Parameter Space Reduction
3.6: One-hot Encoding & Other Processing
1.bcad
2.bcad
3.bcad
4.bcad
<P1>2
<P2>0.674
<P3>False
<P4>ROAD
1.bcad
2.bcad
3.bcad
4.bcad
<P1>0
<P2>0.773
<P3>False
<P4>ROAD
23813
4791
P1 P2 P3 P4
Model 1 0 - False MTB
Model 2 0 12.8 True Road
1314
4512
P2 P3 P4
Model 1 13.1 False MTB
Model 2 12.8 True Road
2395
4512
P2 P3 Road MTB
Model 1 13.1 0 0 1
Model 2 12.8 1 1 0



(a) Full Bike

(b) Image Segmentation

(c) Exploded View

Fig. 4: Segmentation of a bicycle into 7 component parts. Figure

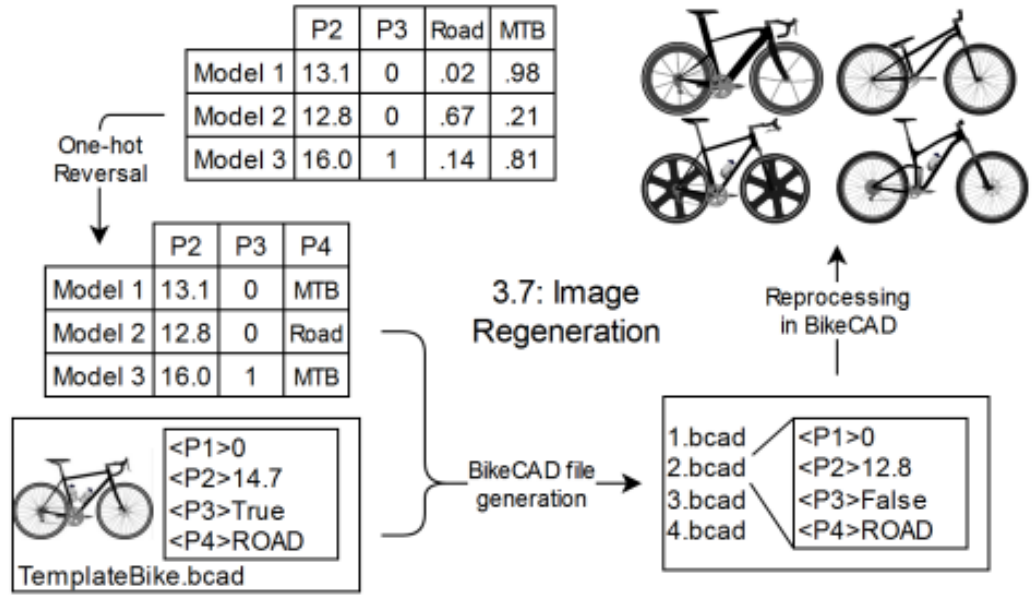
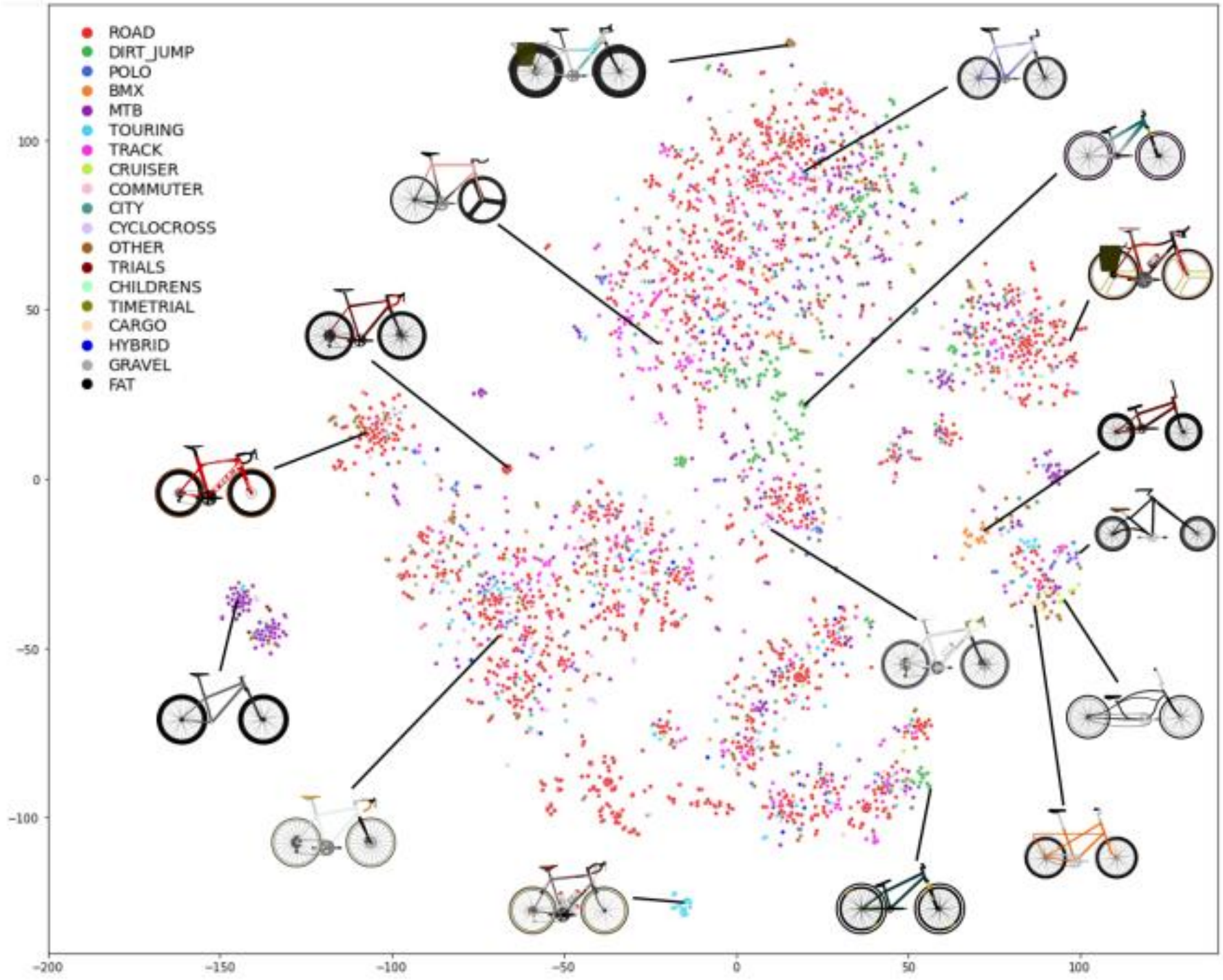


Fig. 5: Process to generate images from parametric data


ROAD
DIRT_JUMP
POLO
BMX
MTB
TOURING
TRACK
CRUISER
COMMUTER
CITY
CYCLOCROSS
OTHER
TRIALS
CHILDRENS
TIMETRIAL
CARGO
HYBRID
GRAVEL
FAT
100
50
0
−50
−100
−200
−150
−100
−50
0
50
100

(a) Images of Original Designs

(b) Parametric VAE Reconstruction

(c) Image VAE Reconstruction

Parametric VAE
Random Sampling

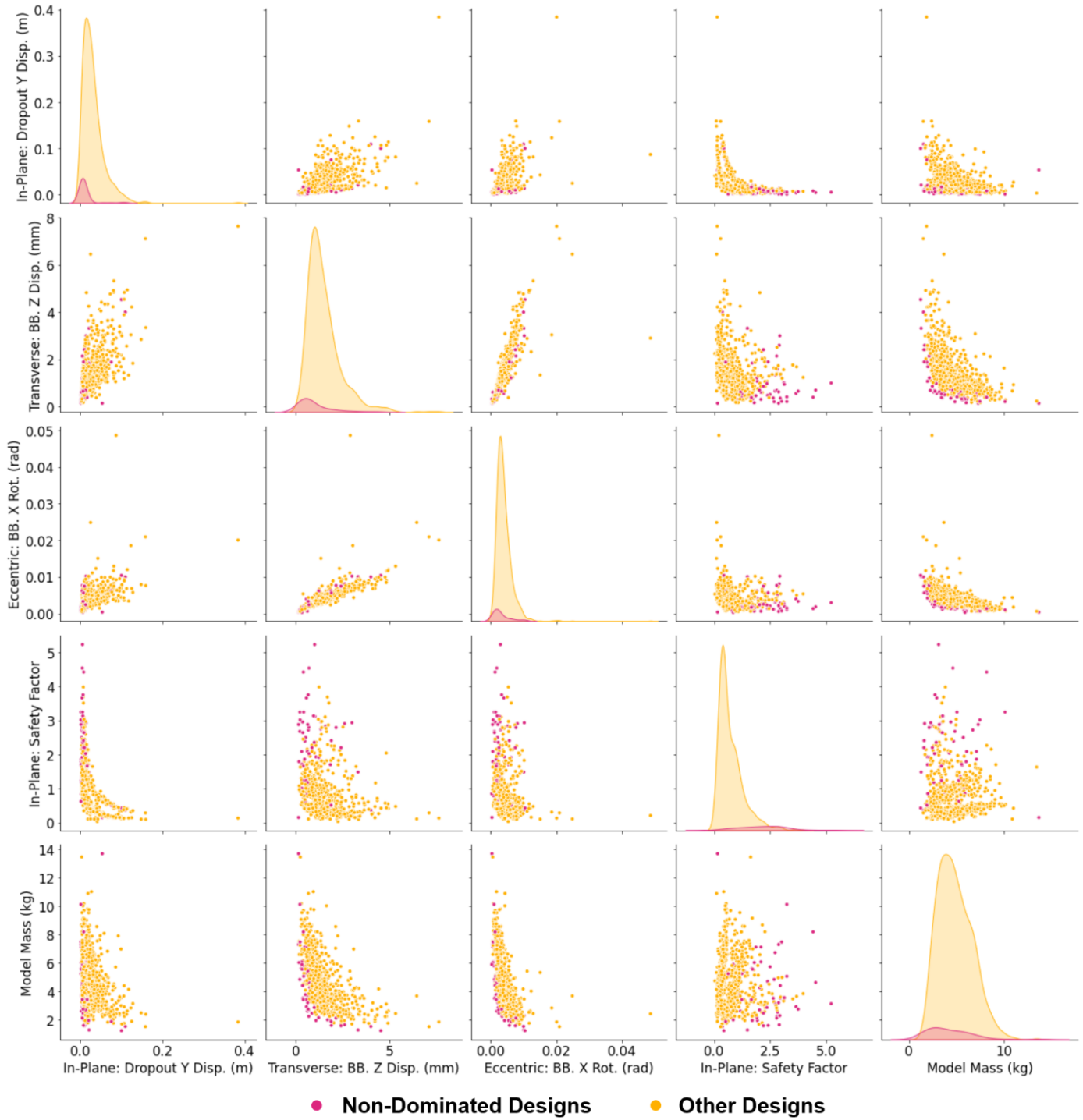
Parametric VAE Latent
Space Interpolation

Image VAE
Random Sampling

Image VAE Latent
Space Interpolation

FRAMED: Data-Driven Structural Performance Analysis of Community-Designed Bicycle Frames

Lyle Regenwetter, Colin Weaver, Faez Ahmed
Massachusetts Institute of Technology
Email: {regenwet, weaverc, faez}@mit.edu,

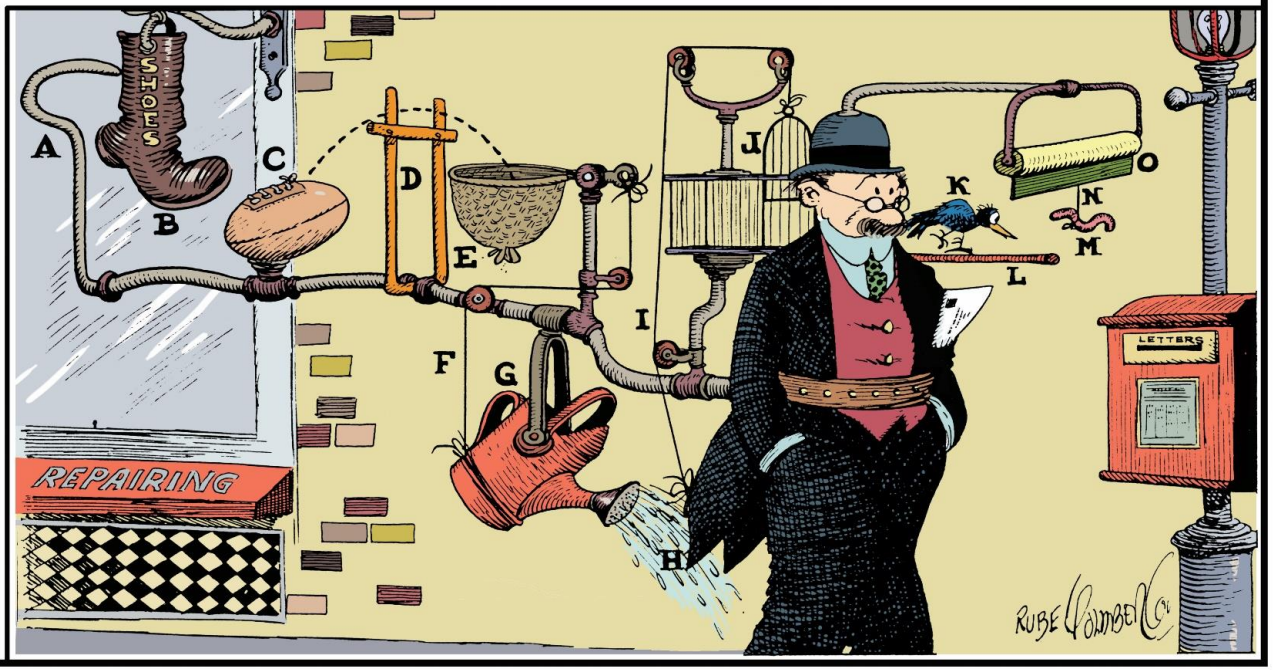


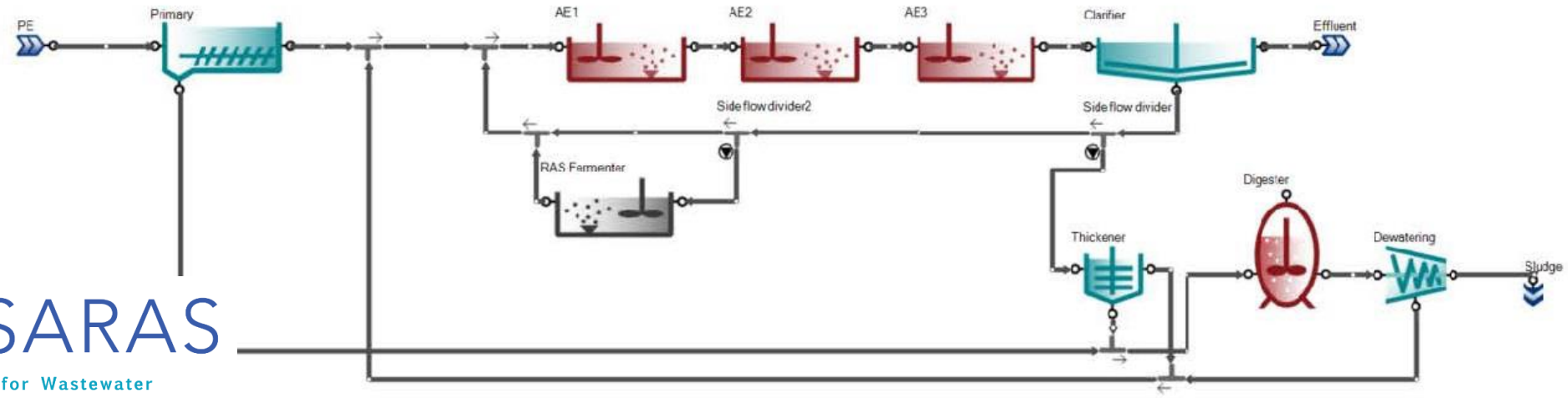
Simple Idea to Keep You From Forgetting To Mail Your Wife's Letter

By Rube Goldberg

PROFESSOR BUTTS GETS CAUGHT IN A REVOLVING DOOR AND BECOMES DIZZY ENOUGH TO DOPE OUT AN IDEA TO KEEP YOU FROM FORGETTING TO MAIL YOUR WIFE'S LETTER.

AS YOU WALK PAST COBBLER SHOP, HOOK (A) STRIKES SUSPENDED BOOT (B) CAUSING IT TO KICK FOOTBALL (C) THROUGH GOAL POSTS (D). FOOTBALL DROPS INTO BASKET (E) AND STRING (F) TILTS SPRINKLING CAN (G) CAUSING WATER TO SOAK COAT TAILS (H). AS COAT SHRINKS CORD (I) OPENS DOOR (J) OF CAGE ALLOWING BIRD (K) TO WALK OUT ON PERCH (L) AND GRAB WORM (M) WHICH IS ATTACHED TO STRING (N). THIS PULLS DOWN WINDOW SHADE (O) ON WHICH IS WRITTEN, "**YOU SAP, MAIL THAT LETTER.**" A SIMPLE WAY TO AVOID ALL THIS TROUBLE IS TO MARRY A WIFE WHO CAN'T WRITE.

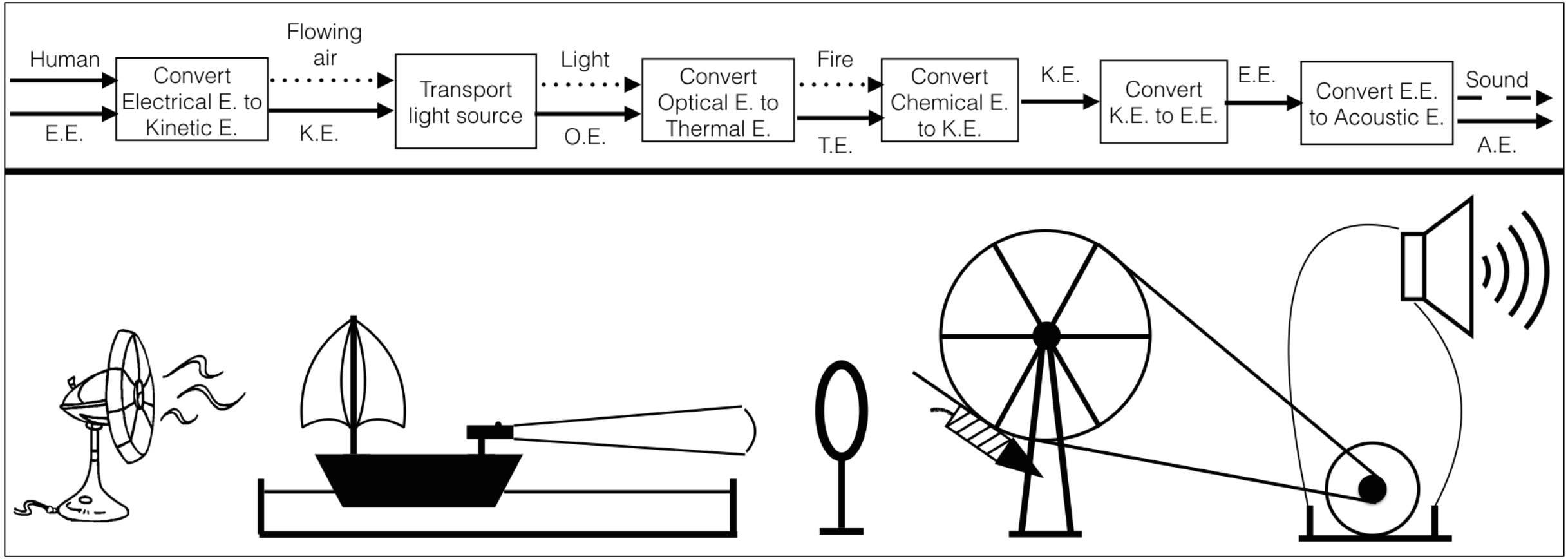




ENSARAS

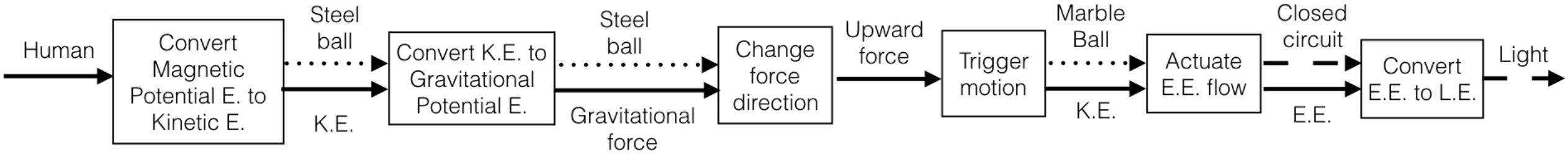
Intelligence for Wastewater

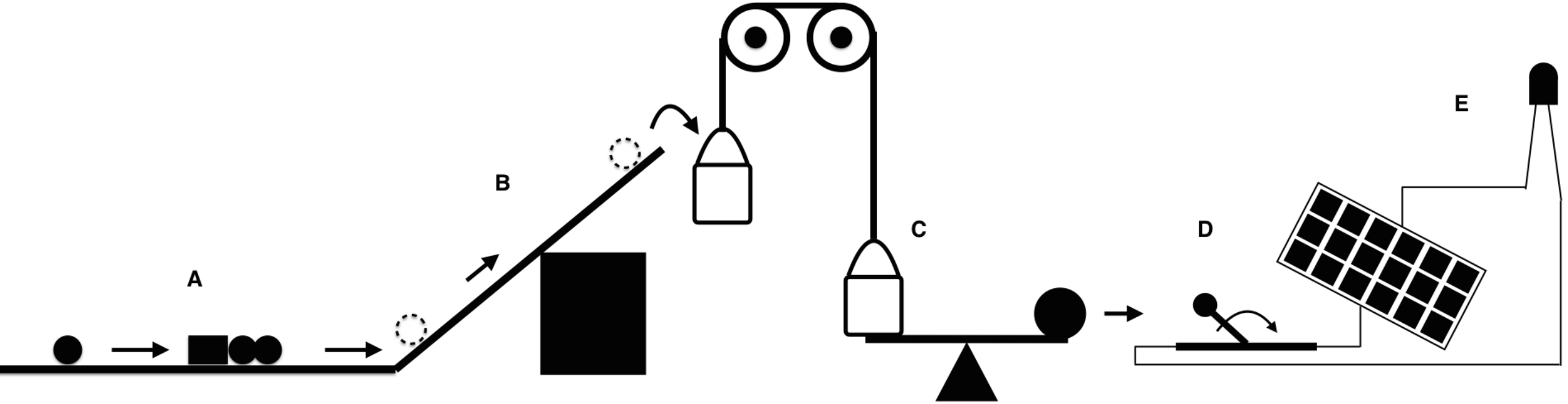
Engineering processes: Rube Goldberg Machines



[Ge, et al., 2018]

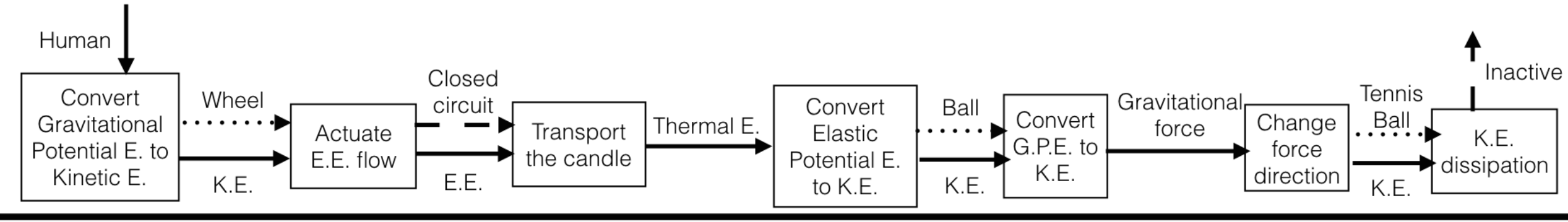
Engineering processes: Rube Goldberg Machines

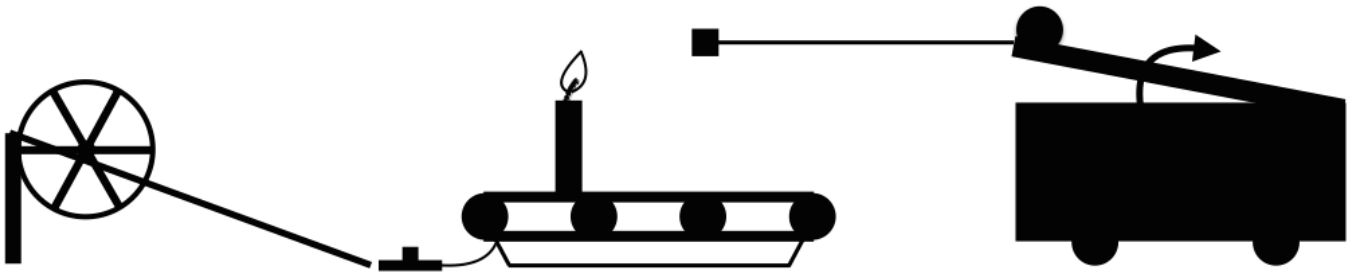


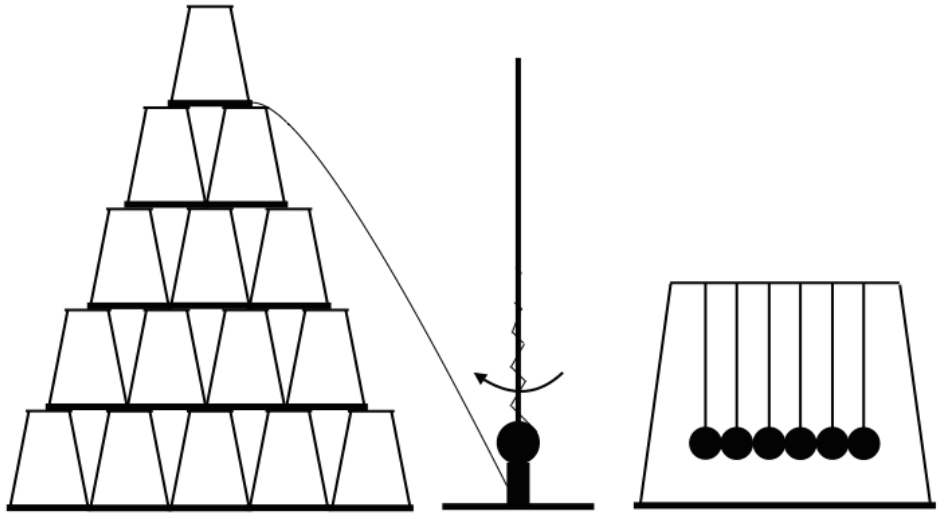


[Ge, et al., 2018]

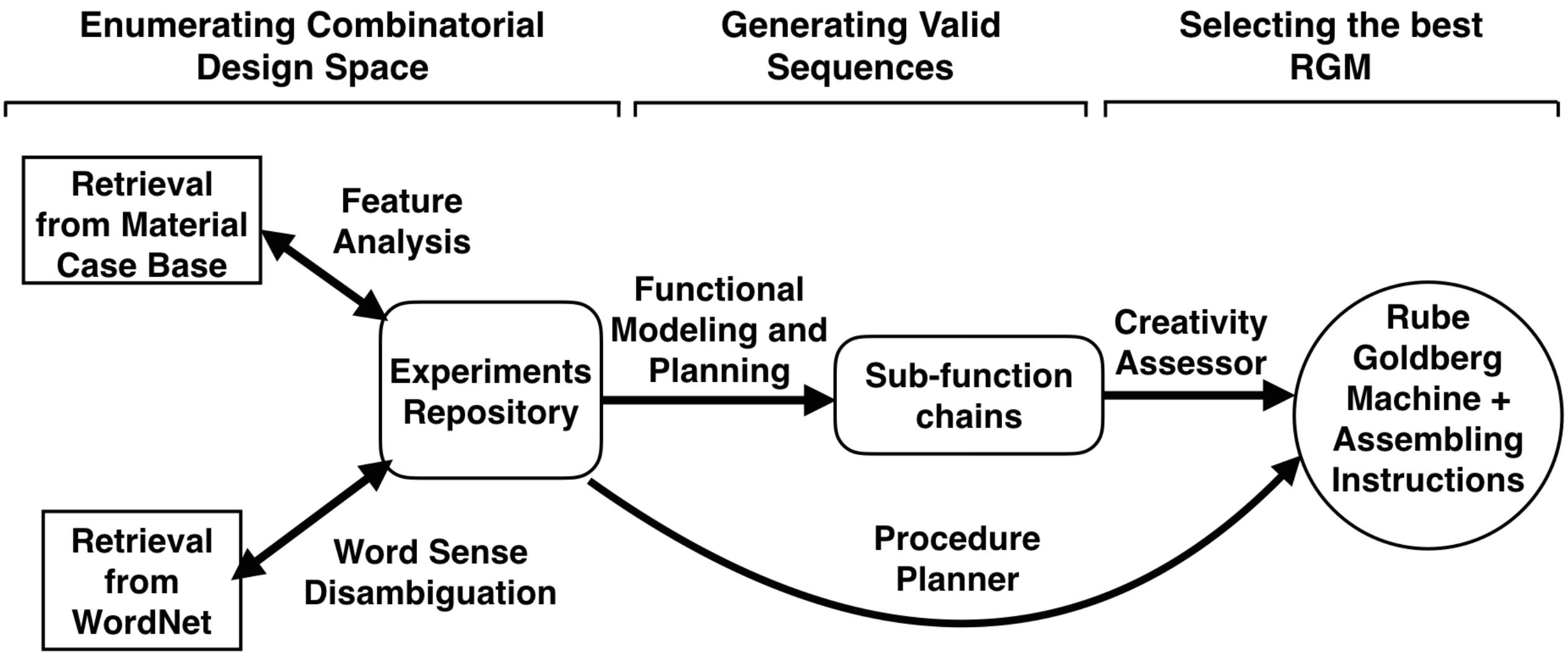
Engineering processes: Rube Goldberg Machines







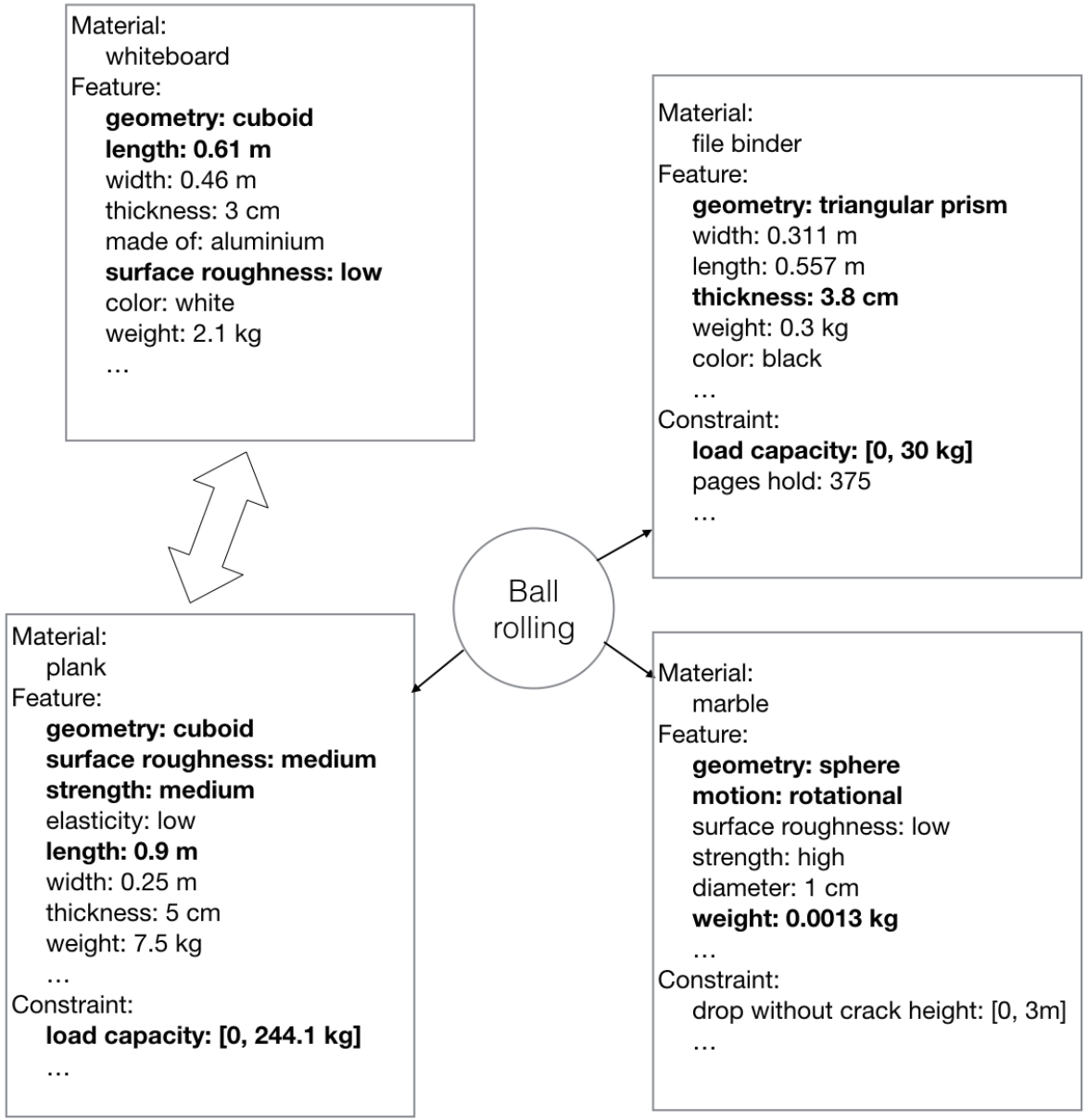
[Ge, et al., 2018]


Enumerating Combinatorial Design Space
Generating Valid Sequences
Selecting the best RGM
Retrieval from Material Case Base
Feature Analysis
Experiments Repository
Functional Modeling and Planning
Sub-function chains
Creativity Assessor
Rube Goldberg Machine + Assembling Instructions
Retrieval from WordNet
Word Sense Disambiguation
Procedure Planner

[Ge, et al., 2018]

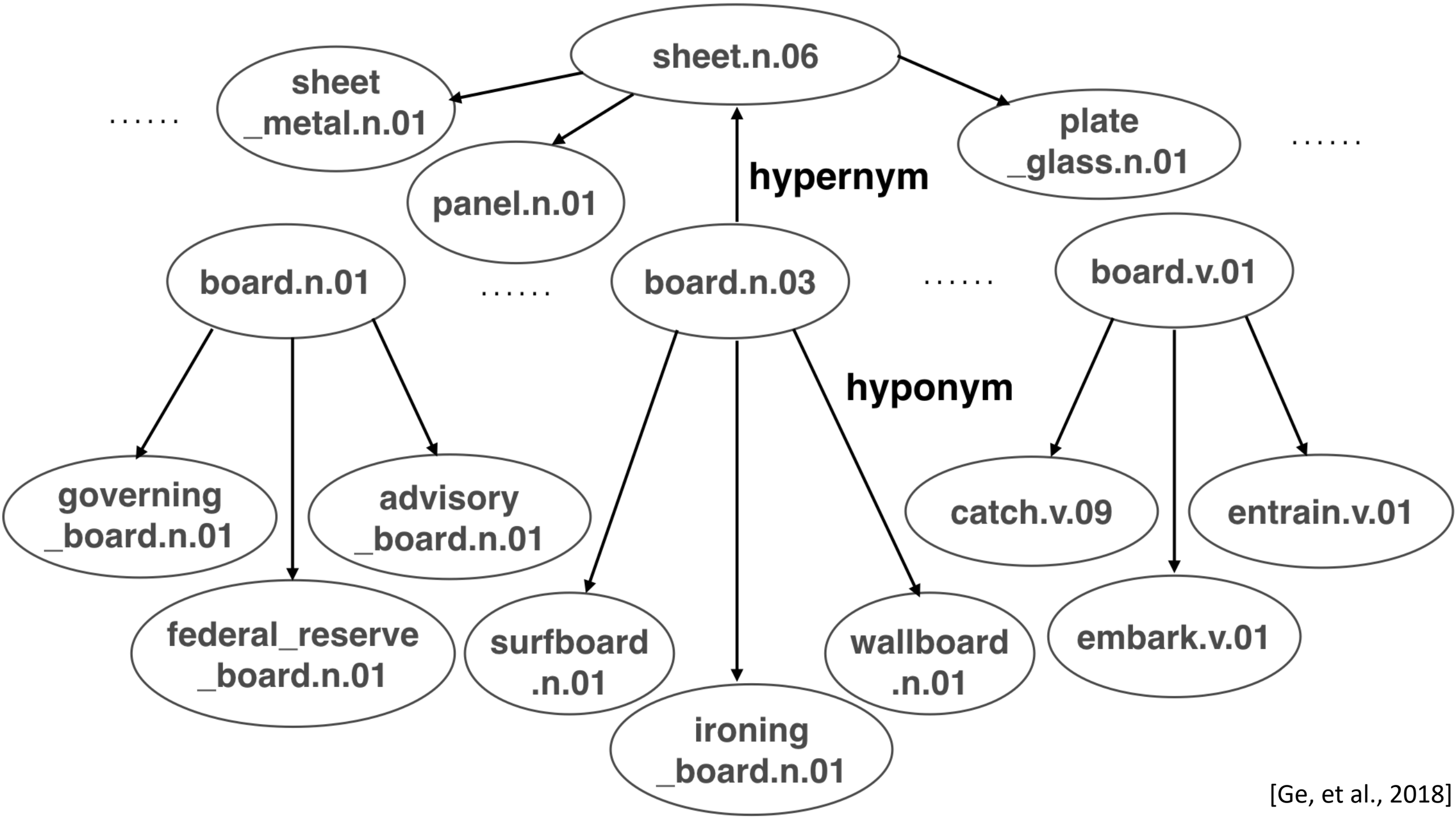
- MaterialProperty
  - Acoustical
  - AppearanceDimensional
    - Weight
    - Geometry
    - Color
    - CrossSection
    - Height
    - Length
    - Width
  - Chemical
  - Electrical
  - Magnetic
  - Mechanical
    - Brittleness
    - CompressiveStrength
    - Ductility
    - Elasticity
    - SurfaceRoughness
    - TensileStrength
    - Viscosity
  - Optical
  - Thermal
    - MeltingPoint
    - ThermalConductivity
    - ThermalExpansion
    - TriplePointTemperature
    - VaporPressure

Material Property Ontology

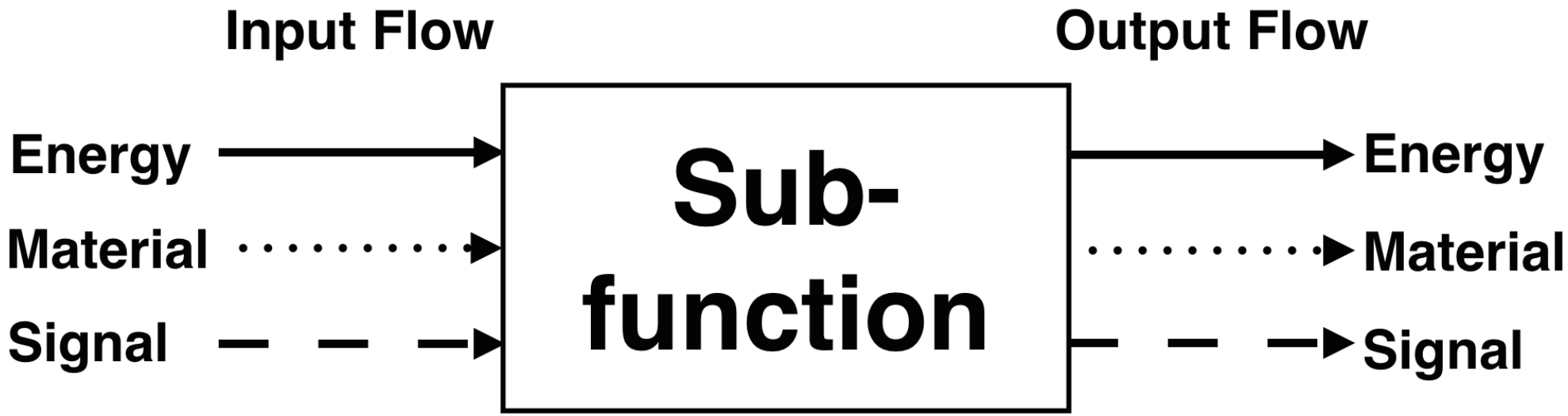


Replacement found by nearest neighbor retrieval

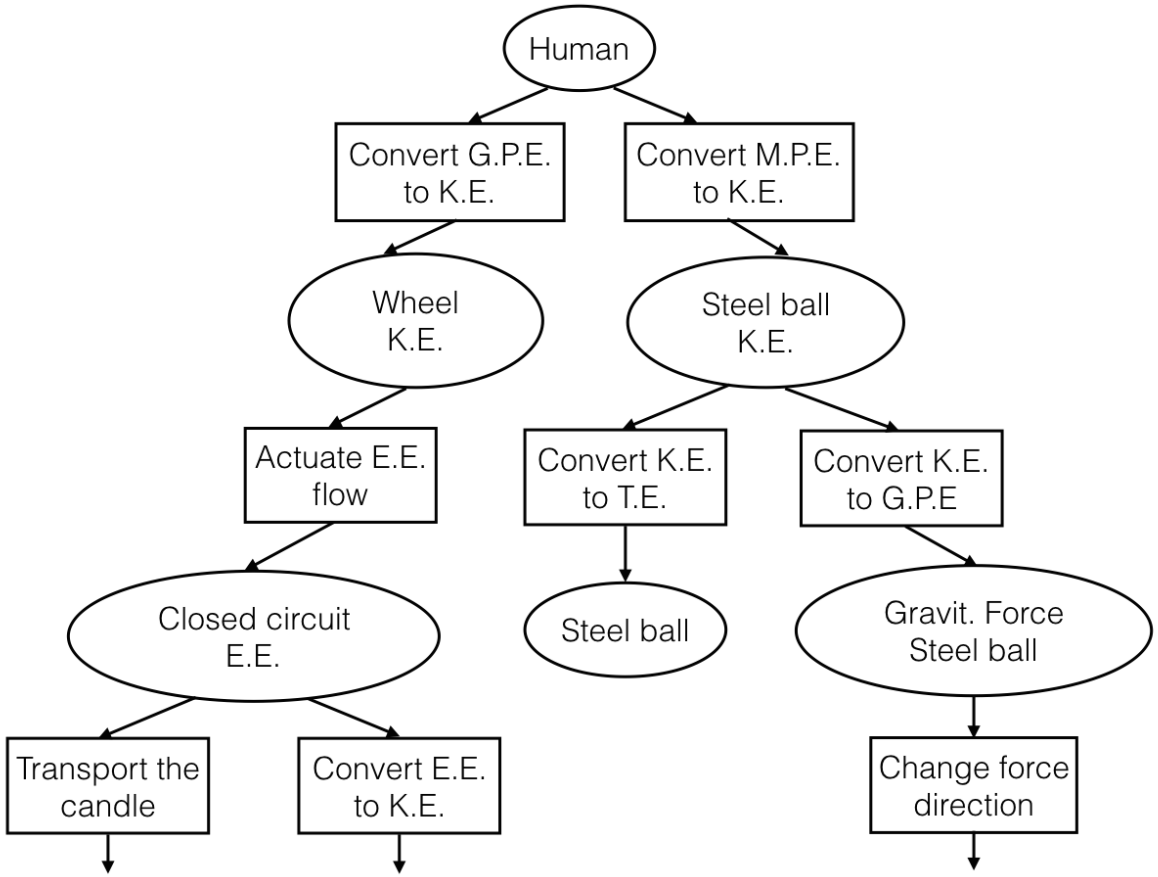
[Ge, et al., 2018]


sheet.n.06
sheet
_metal.n.01
panel.n.01
plate
_glass.n.01
hypernym
board.n.01
board.n.03
board.v.01
governing
_board.n.01
advisory
_board.n.01
hyponym
catch.v.09
entrain.v.01
federal_reserve
_board.n.01
surfboard
.n.01
wallboard
.n.01
embark.v.01
ironing
_board.n.01

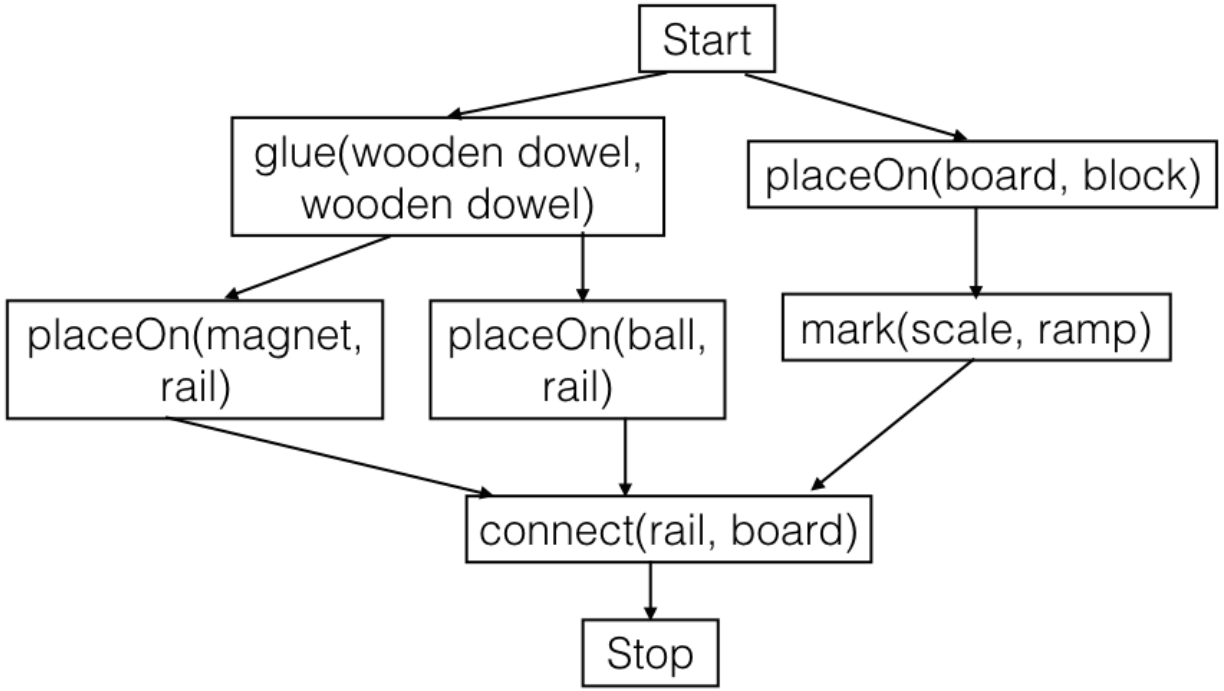
[Ge, et al., 2018]


Input Flow
Output Flow
Energy
Material
Signal
Sub-
function
Energy
Material
Signal

[Ge, et al., 2018]



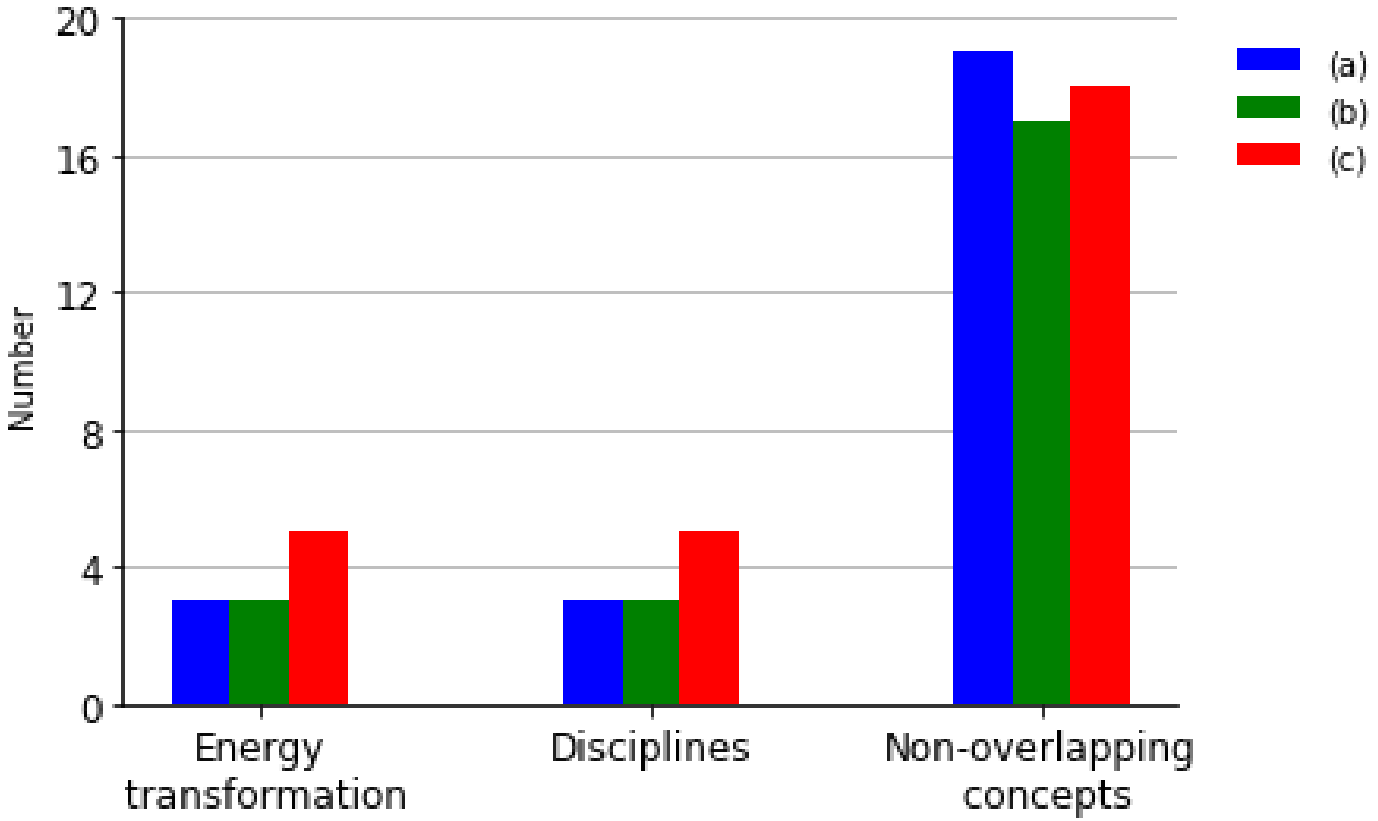
(Part of) state space graph



Assembling plan

[Ge, et al., 2018]

Evaluation of generated Rube Goldberg Machines



[Ge, et al., 2018]

- Generative and creative AI models for engineering and industrial design