현대자동차 버추얼이노베이션리서치랩

인공지능 기반 설계 이론 및 사례 연구

1차) 인공지능 기반 설계의 기초

2020년 9월

강남우

기계시스템학부

숙명여자대학교

Reference

❑ 강의 슬라이드 및 실습코드는 아래의 링크를 참조하세요

- http://www.smartdesignlab.org/dl_hmc.html
  링크주소는 버추얼이노베이션리서치랩 전용입니다.
- 실습조교: 김성신, 유소영, 이성희

❑ 강의 소스

- Andrew Ng의 ML Class (www.holehouse.org/mlclass/)
- Fei-Fei Li & Justin Johnson & Serena Yeung, CS231n: Convolutional Neural Networks for Visual Recognition, Stanford (http://cs231n.stanford.edu/)
- Stefano Ermon & Aditya Grover, CS 236: Deep Generative Models , Stanford (https://deepgenerativemodels.github.io/)
- 모두를 위한 딥러닝 (https://hunkim.github.io/ml/)
- 모두를 위한 딥러닝 시즌 2 (https://deeplearningzerotoall.github.io/season2/lec_tensorflow.html)
- 이활석, Autoencoders (https://www.slideshare.net/NaverEngineering/ss-96581209)
- 최윤제, 1시간만에 GAN(Generative Adversarial Network) 완전 정복하기 (https://www.slideshare.net/NaverEngineering/1-gangenerative-adversarial-network?qid=c53ce33f-6643-4437-8e93-88776c9cebb1&v=&b=&from_search=5)

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What is Deep Learning?

Artificial Intelligence

Any technique which enables
computers to mimic human behaviour.

사람처럼 생각하고 사람처럼 행동하는 기계를 만드는 연구

Machine Learning

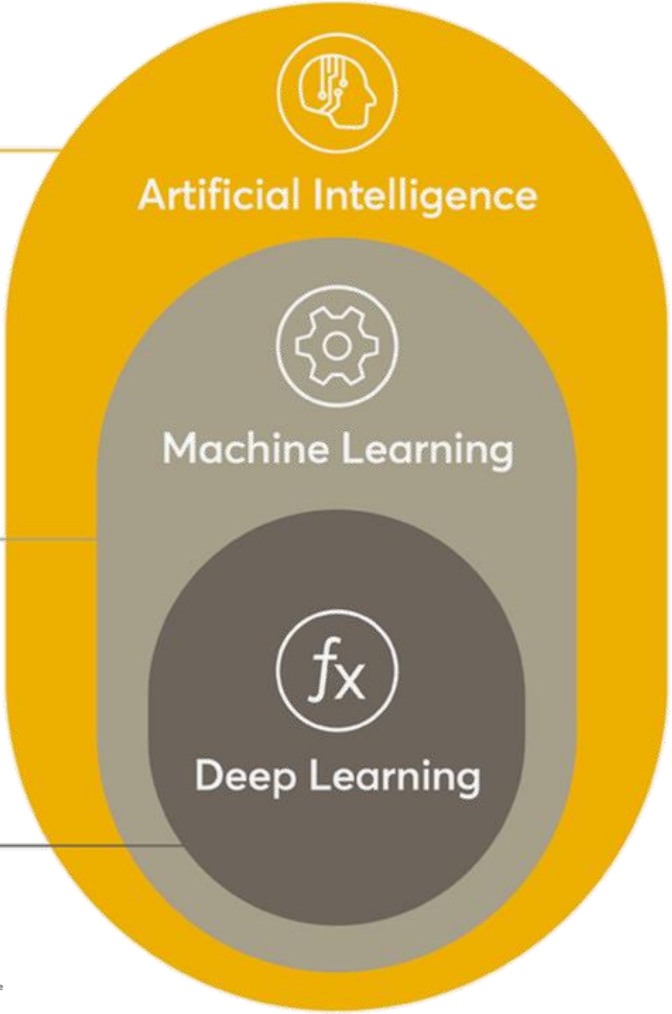
Subset of AI techniques which use
statistical methods to enable machines
to improve with experiences.

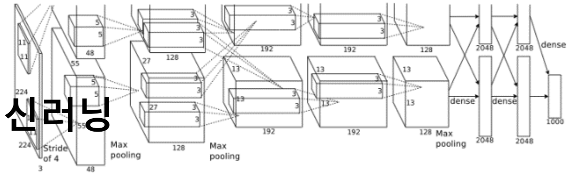
기계가 학습을할 수 있도록하는 인공지능연구의 한 분야

Deep Learning

Subset of ML which makes the
computation of multi-layer
neural networks feasible.

깊은 신경망 구조 기반의 머신러닝

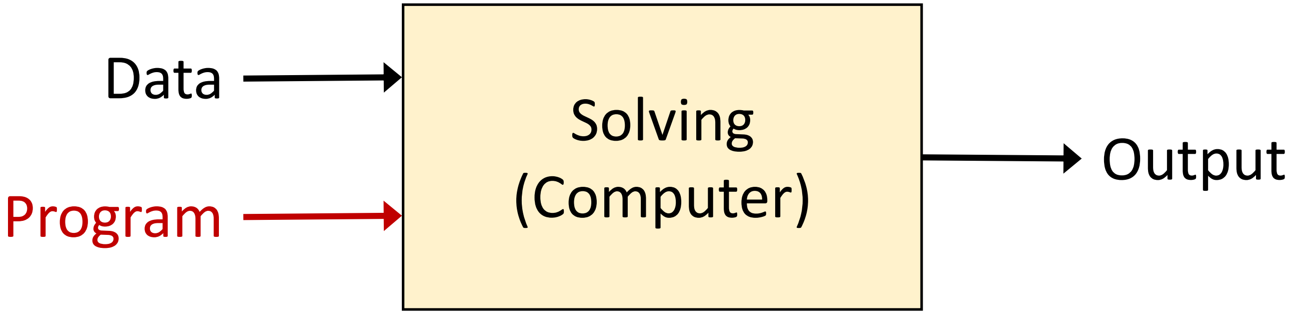




<https://www.nastel.com/blog/simple-guide-ai-machine-learning-deep-learning/>

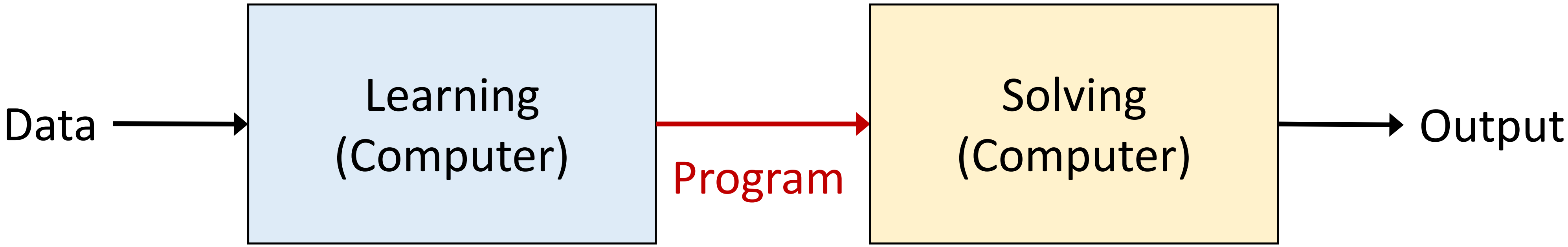
Human vs. ML

- **Human Programming**



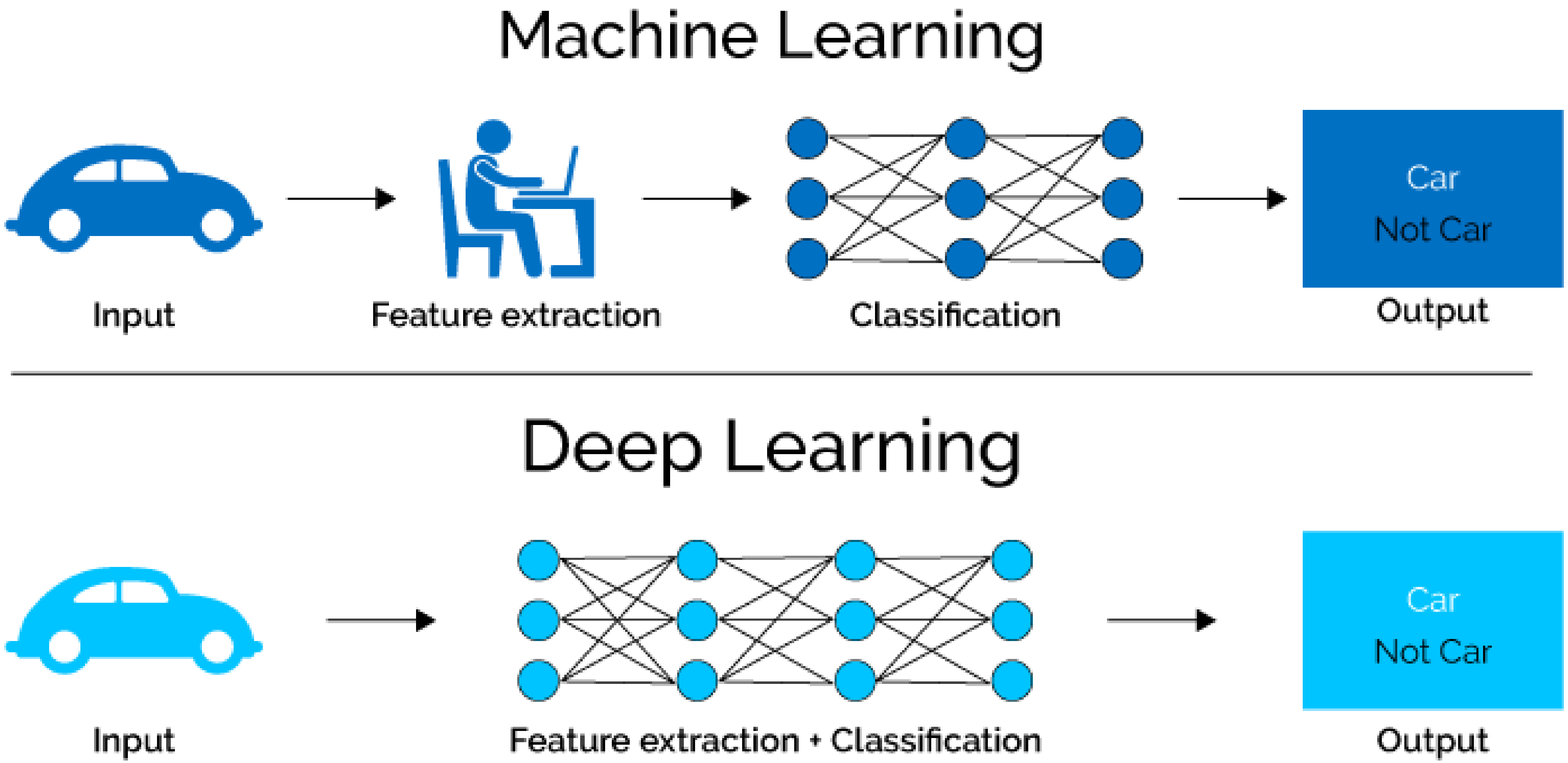
  - 사람이 알고리즘 설계 및 코딩
  - 주어진 문제(데이터)에 대한 답을 출력

- **Automatic Programming (Machine Learning)**



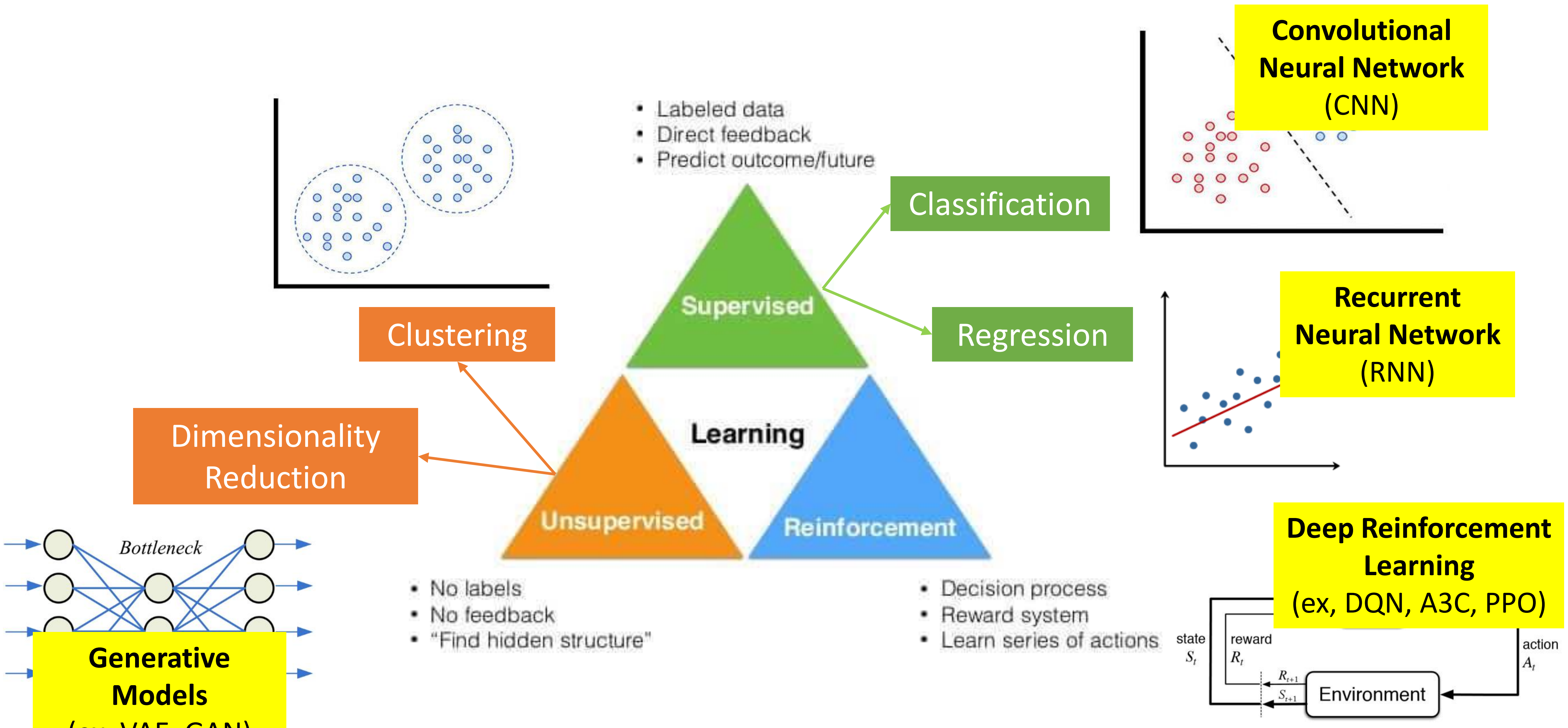
  - 기계가알고리즘을 자동설계
  - 주어진 문제(데이터)에 대한 답을 주는 프로그램을 출력

ML vs. DL



<https://mc.ai/machine-learning-vs-deep-learning-5>

Types of Learning



<https://www.techjini.com/blog/machine-learning/>

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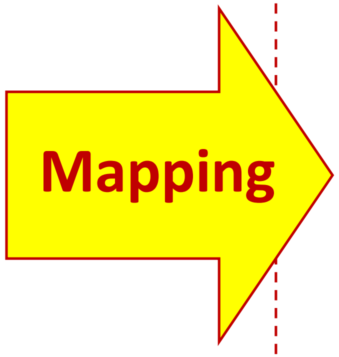
Problem Definition

*"Don't just solve the problem right, but also solve **THE RIGHT PROBLEM**"*

Define Problem

Engineering
(Domain Knowledge)

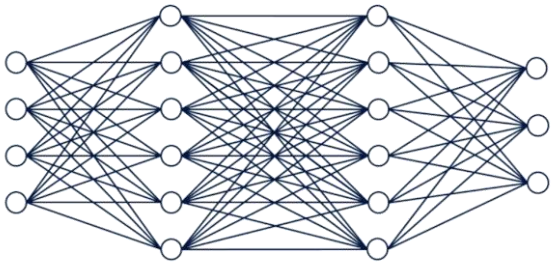
Engineering Problem
(Raw Data)



Solve Problem

Artificial Intelligent
(Data-driven)

AI Problem
(Trainable Data)



Many people can do

Only domain experts can do

Research Question

"Can AI Design Engineering Systems?"

ME (Problems)

Robot

Autonomous Vehicle

Healthcare and Bio

Smart Factory

Design

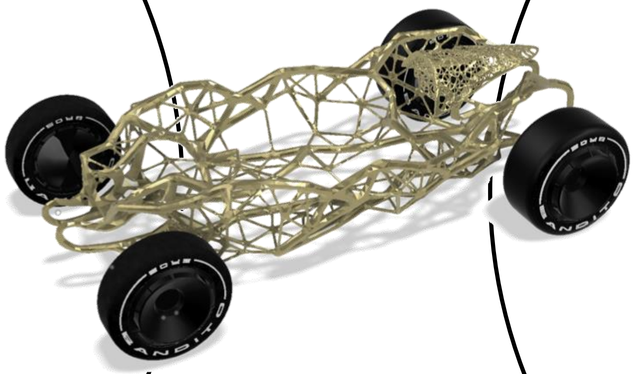
(Design Optimization CAD/CAE/CAM)

Materials Design

Prognostics and Health Management (PHM)

⋮

X* + *AI



AI (Methods)

Function Approximation

Prediction

Generation

Clustering

Classification

Anomaly Detection

Dimensionality Reduction

Domain Adaptation

Transfer Learning

Reinforcement Learning

⋮

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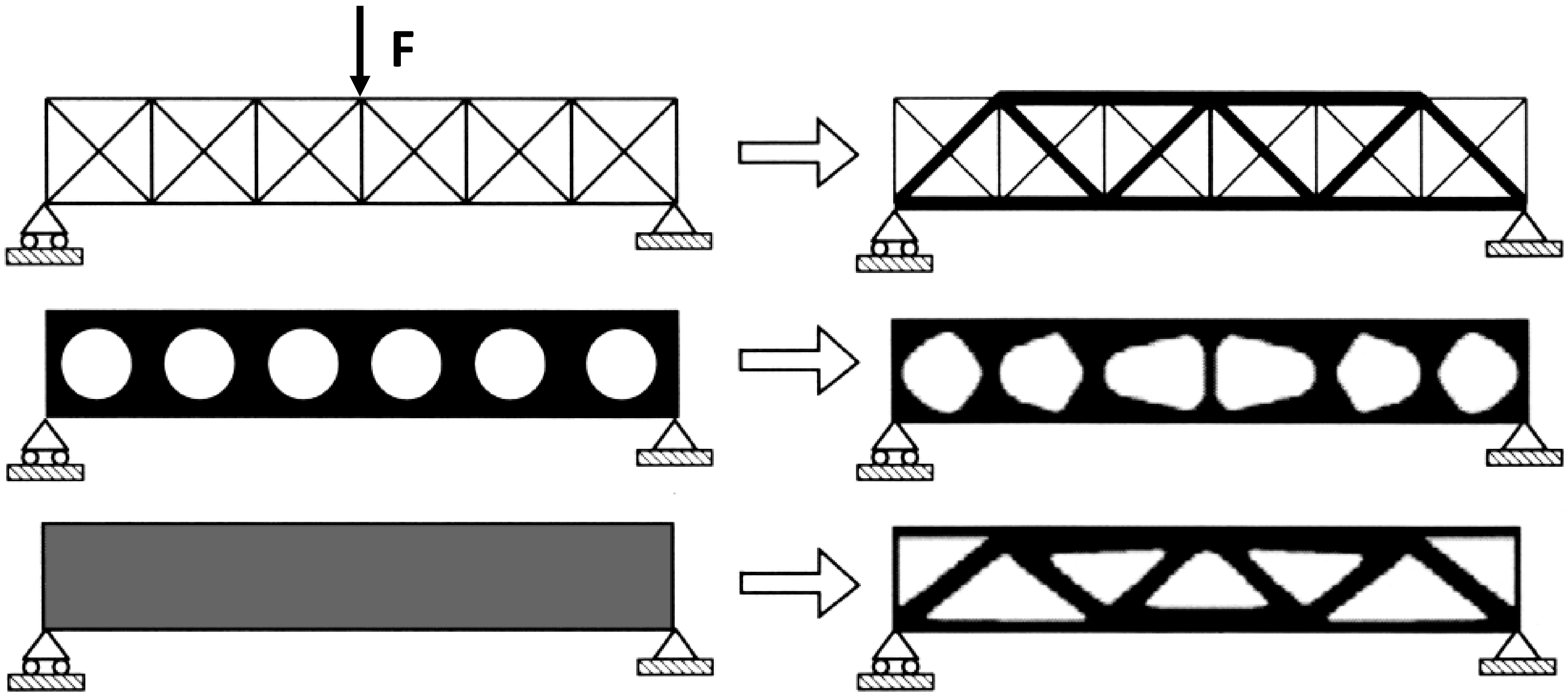
Design Optimization

Size Optimization

Shape Optimization

Topology Optimization



<Bendsøe, M. P., and Sigmund, O., 2003, Topology Optimization: Theory, Methods and Applications, Springer, Berlin>

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Topology Optimization

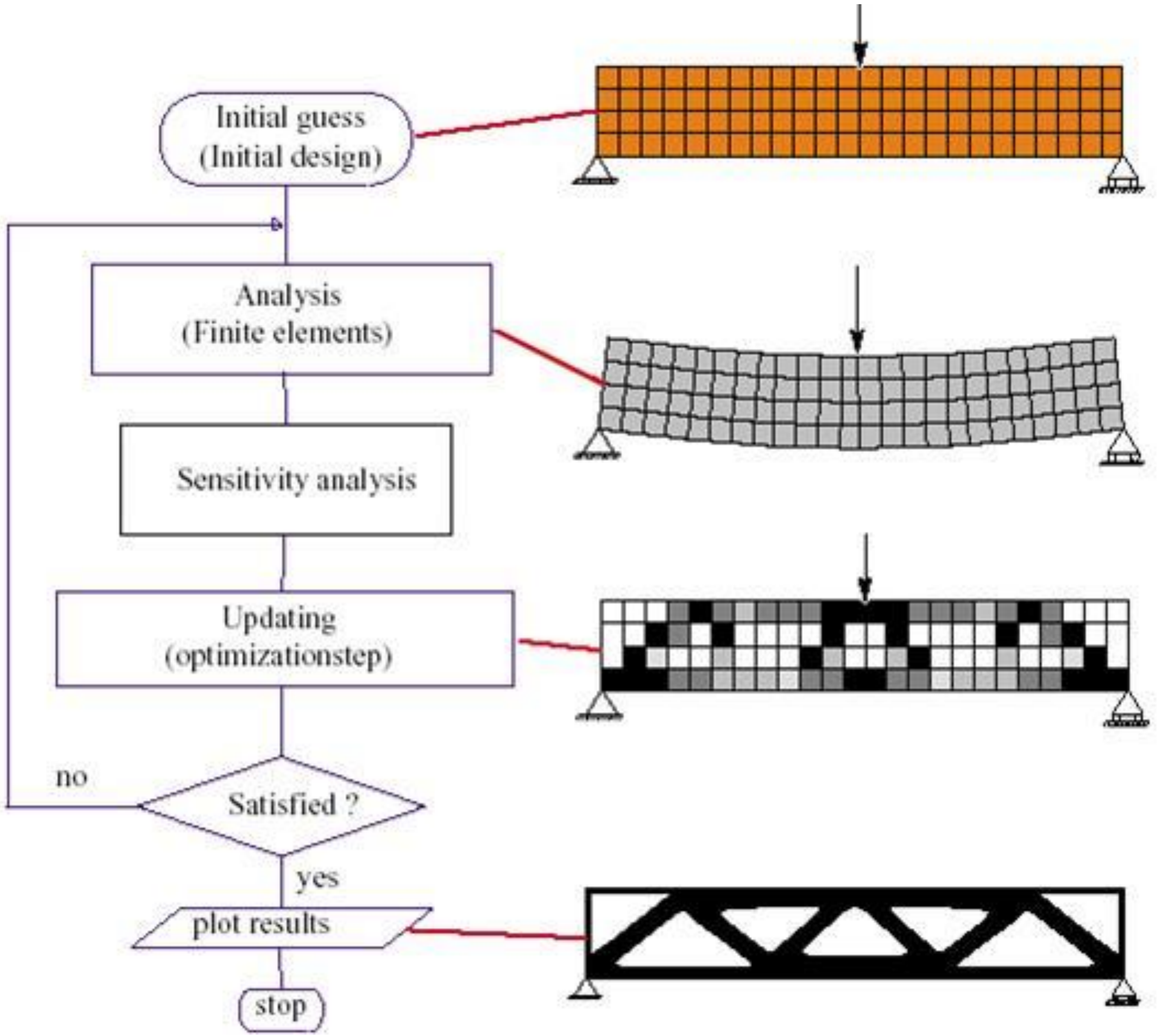
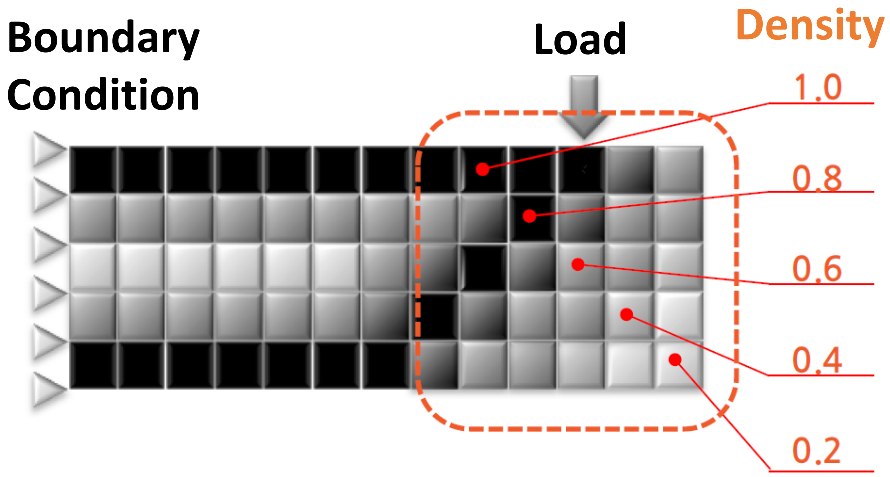


Image Pixels for Deep Learning?



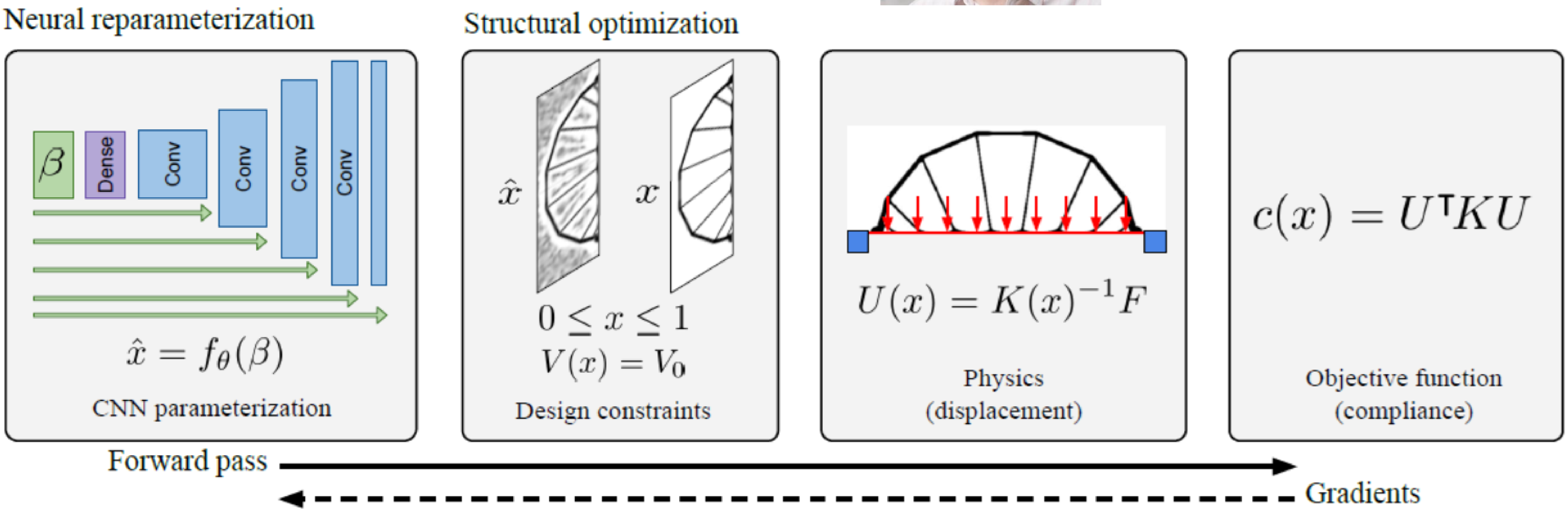
- **Objective:** Minimize Compliance (=Maximize Stiffness)
- **Design Variables:** Density
- **Constraint:** Volume Fraction

<Bendsøe, M. P., and Sigmund, O., 2003, Topology Optimization: Theory, Methods and Applications, Springer, Berlin>
<http://www.midasuser.com/>

Topology Optimization by Google

Stephan Hoyer

"I am a physicist, data scientist and software engineer."

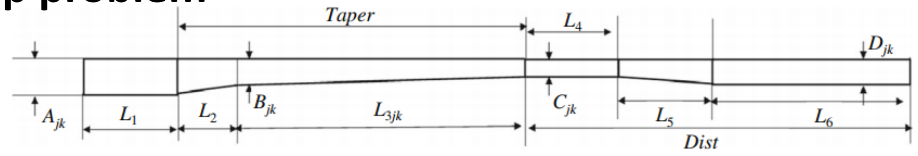


<Hoyer, S., Sohl-Dickstein, J., & Greydanus, S. (2019). Neural reparameterization improves structural optimization. arXiv preprint arXiv:1909.04240.>

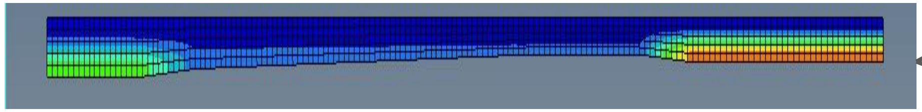
Simulation based Design Optimization + Deep Learning

Design Optimization

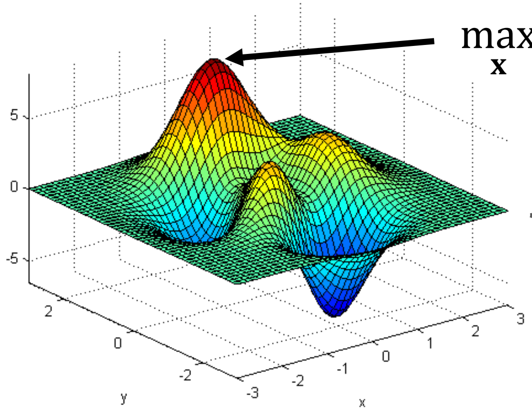
① **Set up problem**



② **Build simulation & meta models**



③ **Solve problem**



$$\max_{\mathbf{x}} \ \text{stiffness}(\mathbf{x})$$

Deep Learning Approach

- Dimensionality Reduction
- Parameterization
- Data Generation
- Prediction
- End-to-End Learning
- Reinforcement Learning

Meta Modeling vs. Deep Neural Network

Same goal: Approximate the true function with data

"All models are wrong! But some are useful.." – George E.P. Box

$$f(\mathbf{x}) \approx f_\theta(\mathbf{x}) \text{ given } \{\mathbf{x}^{(i)}, y^{(i)}\}_{i=1}^{N}$$

Meta modeling (Surrogate modeling)

Classic approach

$$\min_\theta L(f_\theta(\mathbf{x}), \mathbf{y})$$

$$L \propto (y^{(i)} - f_\theta(\mathbf{x}^{(i)}))^2$$

Mean Squared Error (MSE)

- Use design variables as input (low dimensions)

$\approx$

Deep neural network

Maximum Likelihood approach

$$\min_\theta[-\log(p(y|f_\theta(\mathbf{x})))]$$

Negative log-likelihood

When Gaussian distribution,

$$L \propto (y^{(i)} - f_\theta(\mathbf{x}^{(i)}))^2$$

Mean Squared Error (MSE)

- Not limited to design variables as input (high dimensions)
- Need a lot of data
- Need assumptions for backpropagation
- More powerful and generalizable

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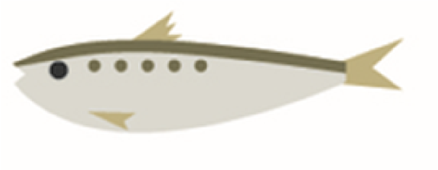
Design Optimization vs. Reinforcement Learning

Design Optimization

Consume no time for exploring solutions (training),
but time for new optimization (testing)

for Fixed Requirements

for Single Decision



Give a man a fish

VS.

Reinforcement Learning

Consume time for exploring solutions (training),
but no time for new solution (testing)

for Different Requirements (**Generalization**)

for Sequential Decisions
(Possible convert single decision to sequential decisions)

Teach a man to fish

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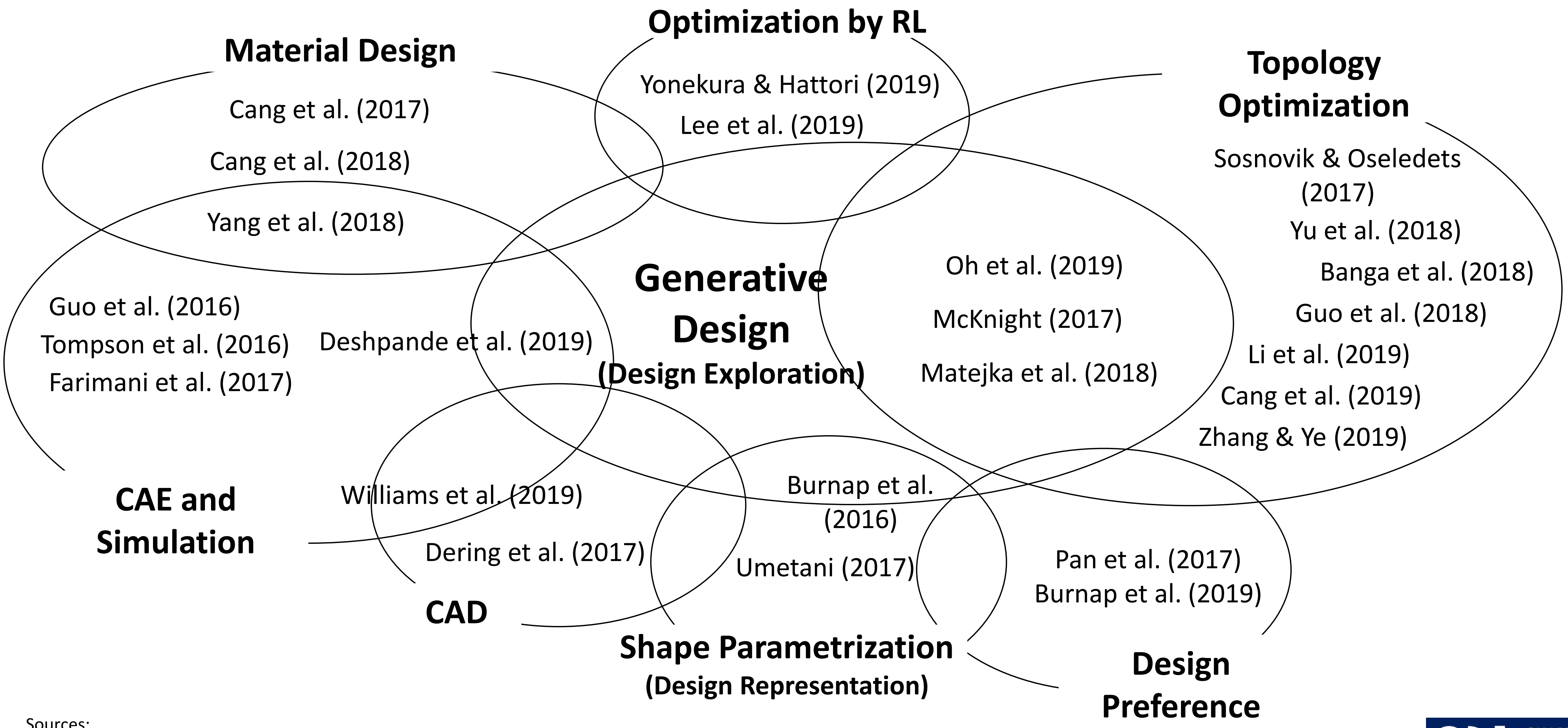
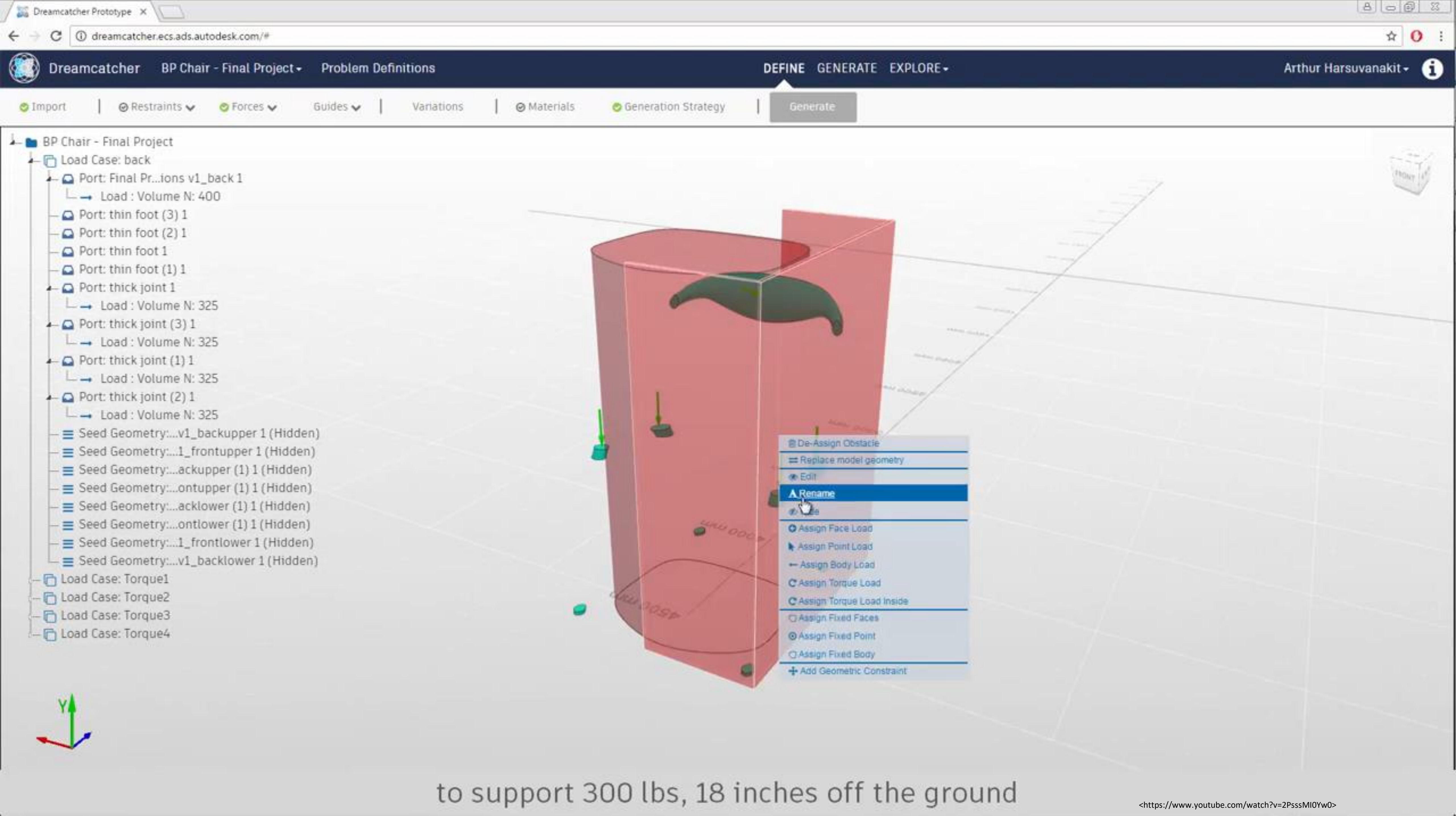
Engineering Design + Deep Learning

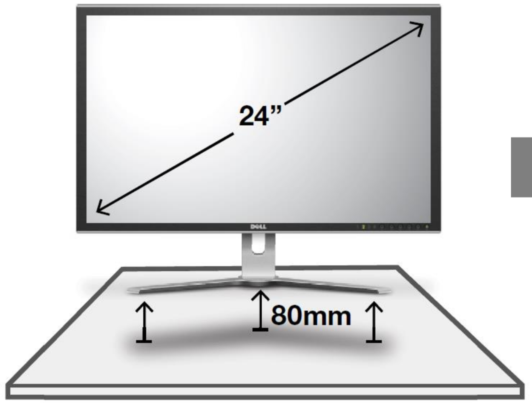


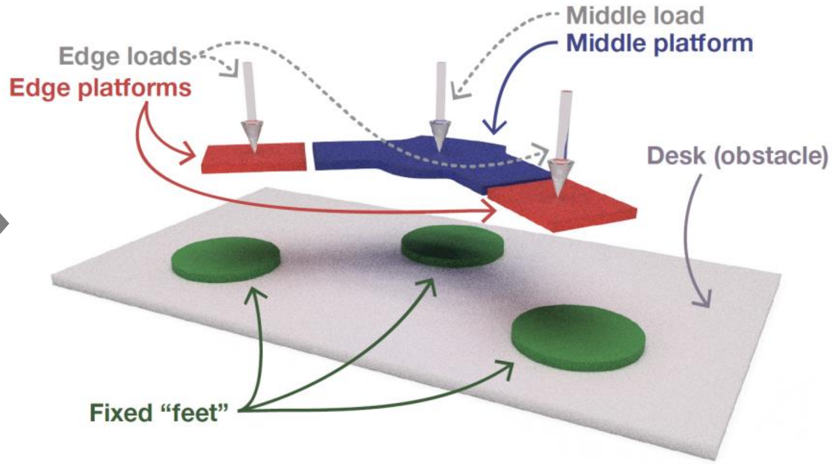
Sources:
- *Journal of Mechanical Design*
- *Structural and Multidisciplinary Optimization*

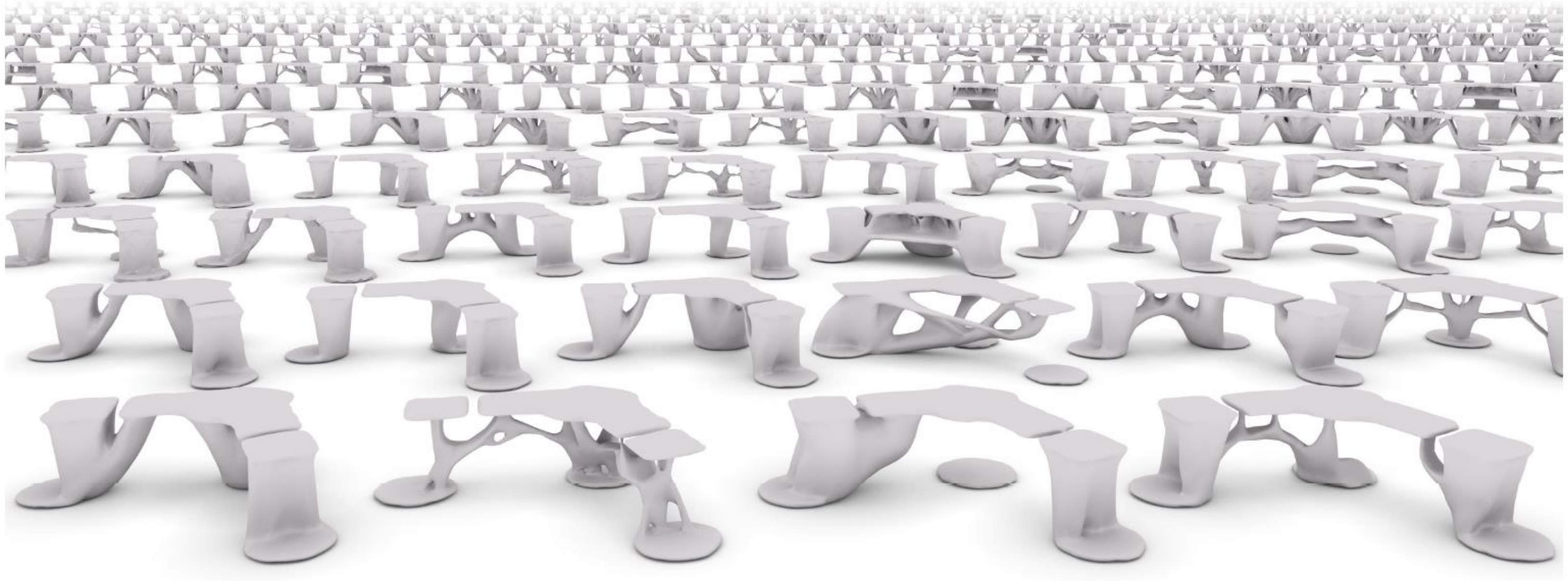


<https://www.youtube.com/watch?v=2PsssMI0Yw0>

What is Generative Design?



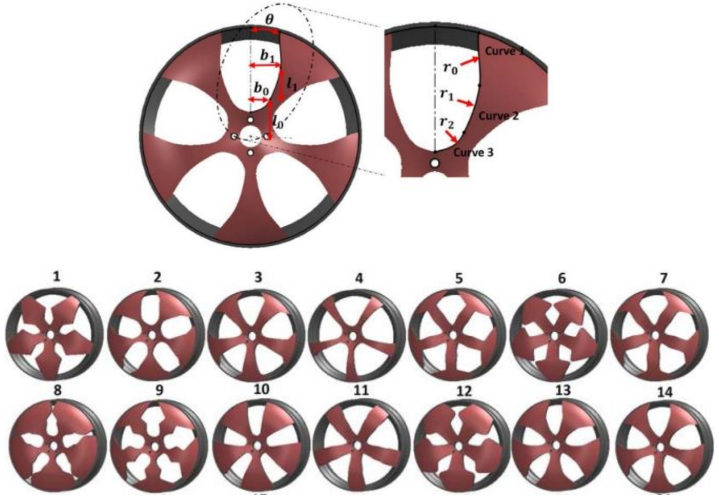




	5	Middle Loads
	5	Edge Loads
	3	Voxel Sizes
	3	Mu Values
X	74	Iterations
	16,800	Design Problems
	16,800	Optimal Designs

<Matejka, J., Glueck, M., Bradner, E., Hashemi, A., Grossman, T., & Fitzmaurice, G. (2018, April). Dream Lens: Exploration and Visualization of Large-Scale Generative Design Datasets. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (p. 369). ACM>

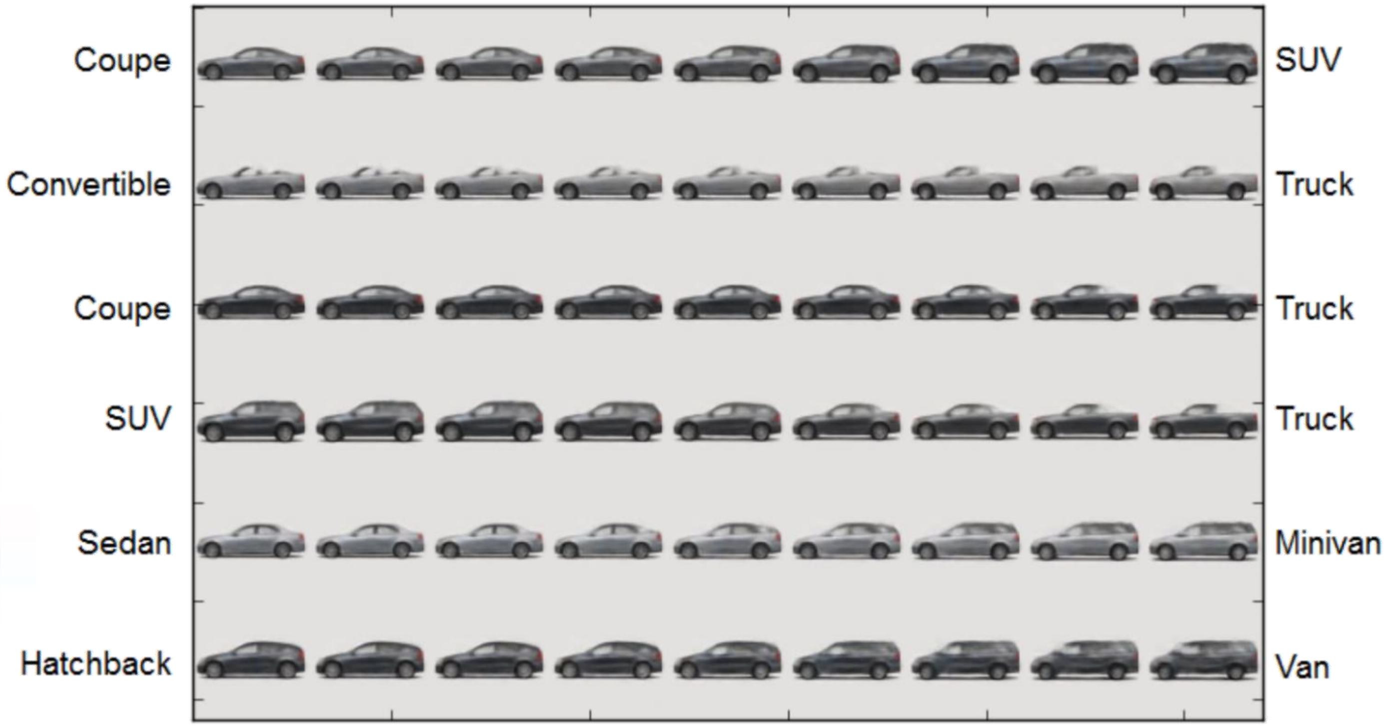
What is Generative Design?

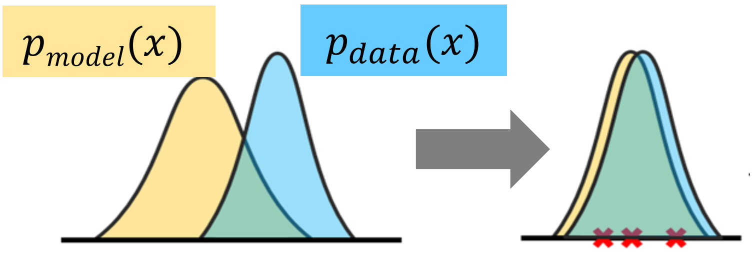


	Generative Design	Topology Optimization	Parametric Design
Objective	Explore feasible *design sets* (*thousands of designs*)	Find the *optimal design*	Explore *design sets*
Method	Vary parameters of *problem definition* in Topology Optimization	Optimize material layout within given design space	Vary parameters of *geometry* directly

Kang (2019)

What is Deep Learning?



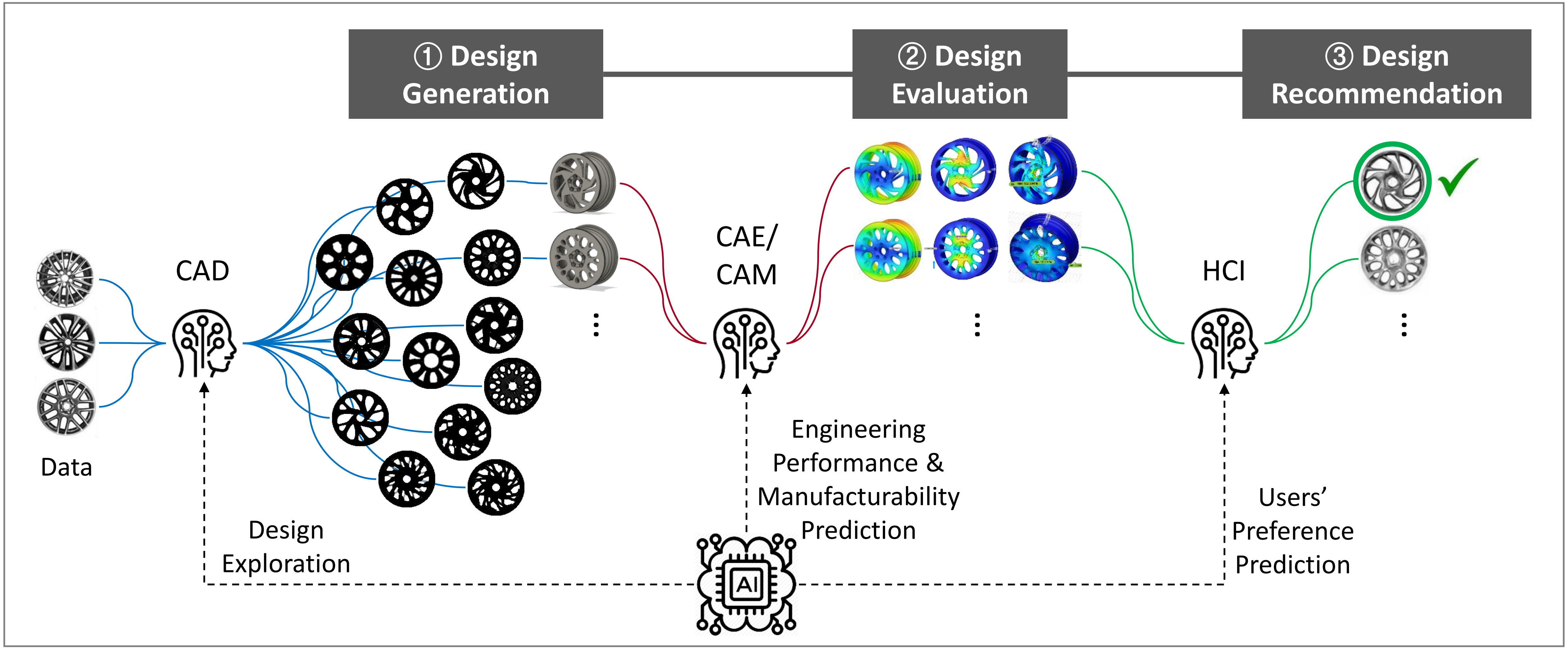


Want to learn $p_{model}(x)$ similar to $p_{data}(x)$

Burnap et al (2016)

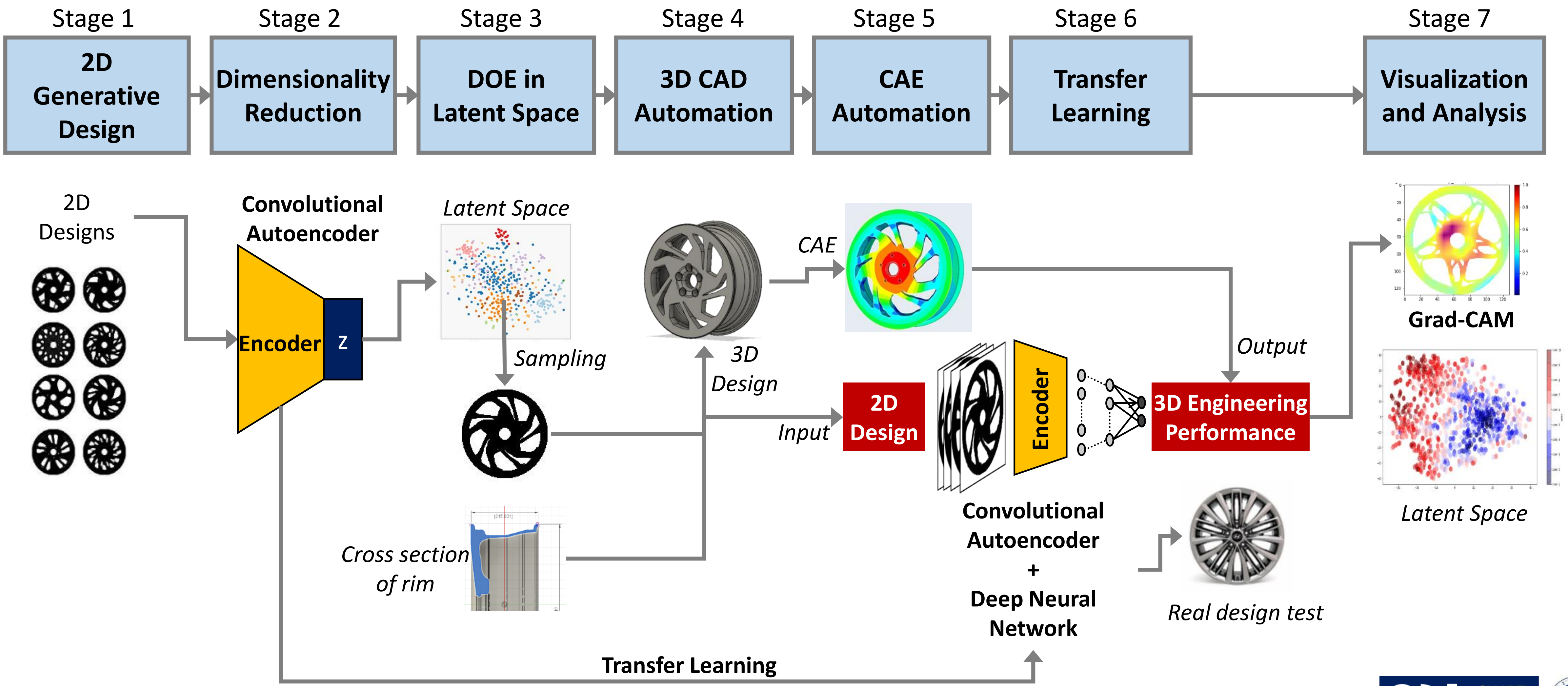
Design Automation Process

AI-based Generative Design



Design Automation Process

❖ Integrating Deep Learning into CAD/CAE Framework



Yoo et al (2020)

What Questions Do You Have?

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www.smartdesignlab.org