KAERI

바이올린, 최적설계 그리고 인공지능

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(ygyu@kaeri.re.kr, yoyogo@gmail.com)

2019.10.2

Korea Atomic Energy Research Institute

AiFrenz
멤버쉽 DAY

바이올린, 최적설계 그리고 인공지능

□ 일시 : 2019. 10. 2. (수) 오후 7~9시

□ 장소 : 대전 대덕테크비즈센터(TBC) 1층 콜라보홀

□ 발표 : 유용균 (한국원자력연구원)

- 바이올린의 최적설계
- 최적설계 분야의 인공지능 적용
- 덕질의 과거, 현재, 미래

□ 차후 일정

- 10/16 산업 인공지능 (마키나락스 윤성호)

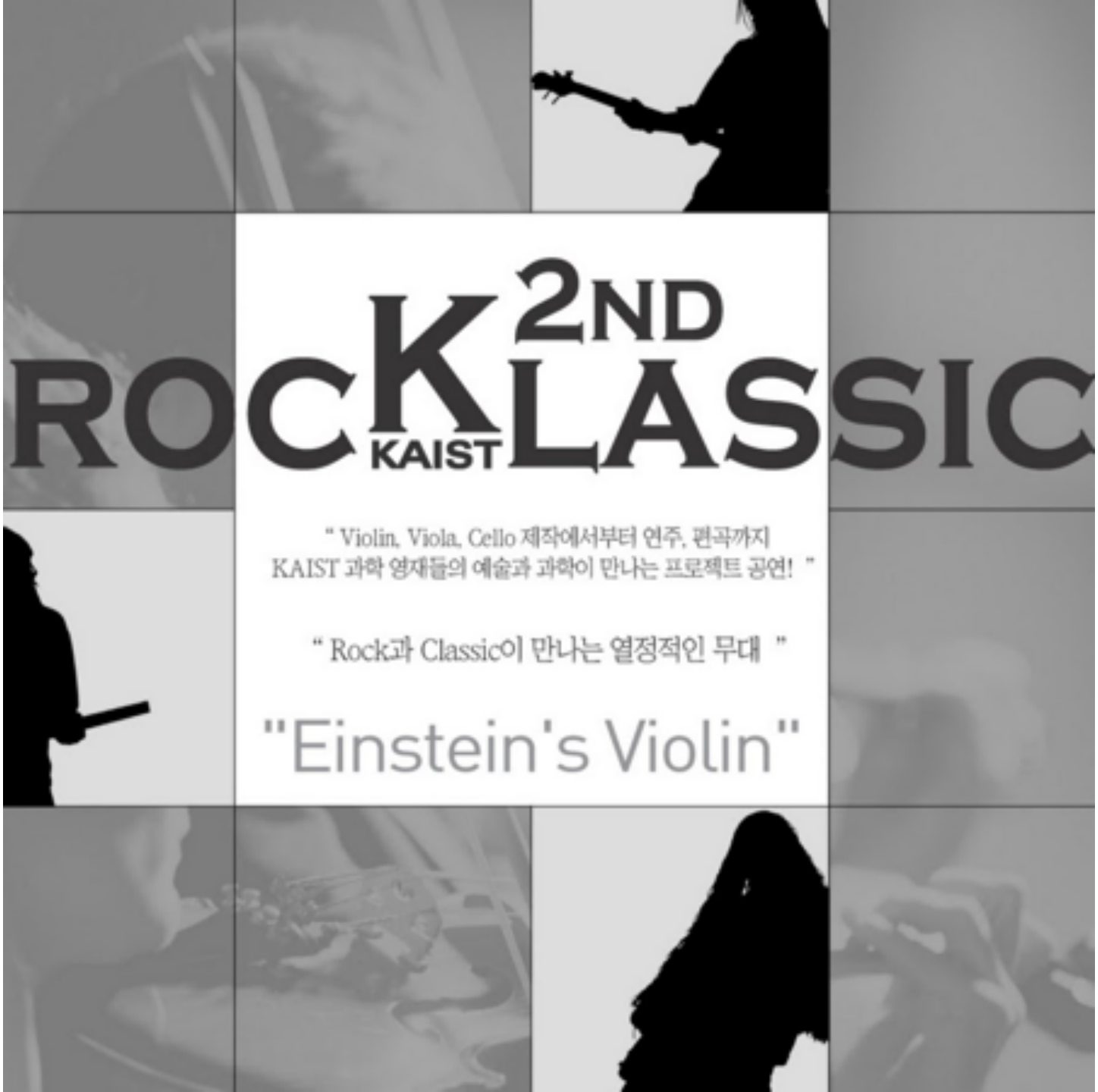
□ 문의: 유용균 yoyogo@gmail.com, 김귀훈 kiwi7580@gmail.com

□ 후원: 연구개발특구진흥재단

바이올린

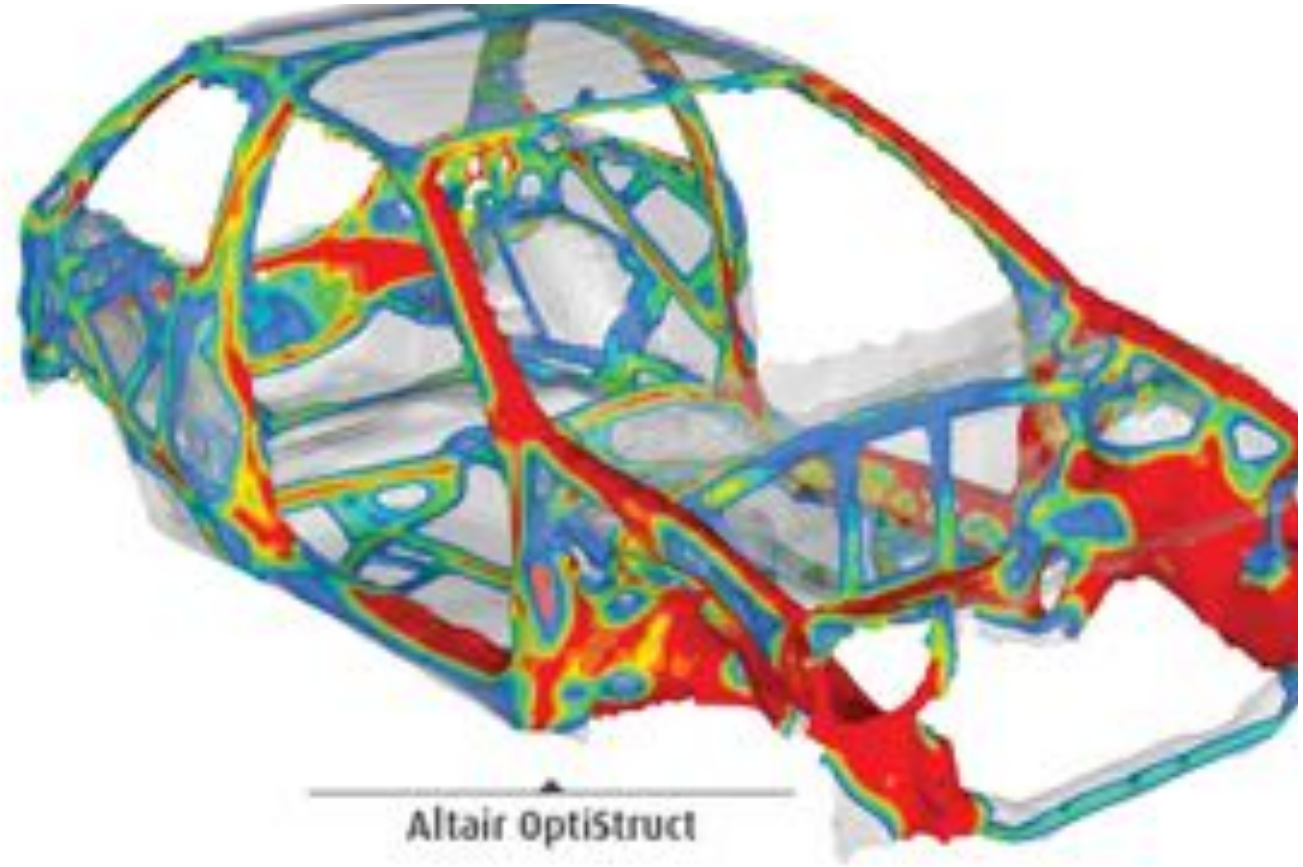
저의 대학원 생활은 방황과 교수님의 무관심 덕분에..


WORLD
WARCRAFT
CLASSIC


2ND
ROCK KAIST CLASSIC
" Violin, Viola, Cello 제작에서부터 연주, 편곡까지
KAIST 과학 영재들의 예술과 과학이 만나는 프로젝트 공연! "
" Rock과 Classic이 만나는 열정적인 무대 "
"Einstein's Violin"

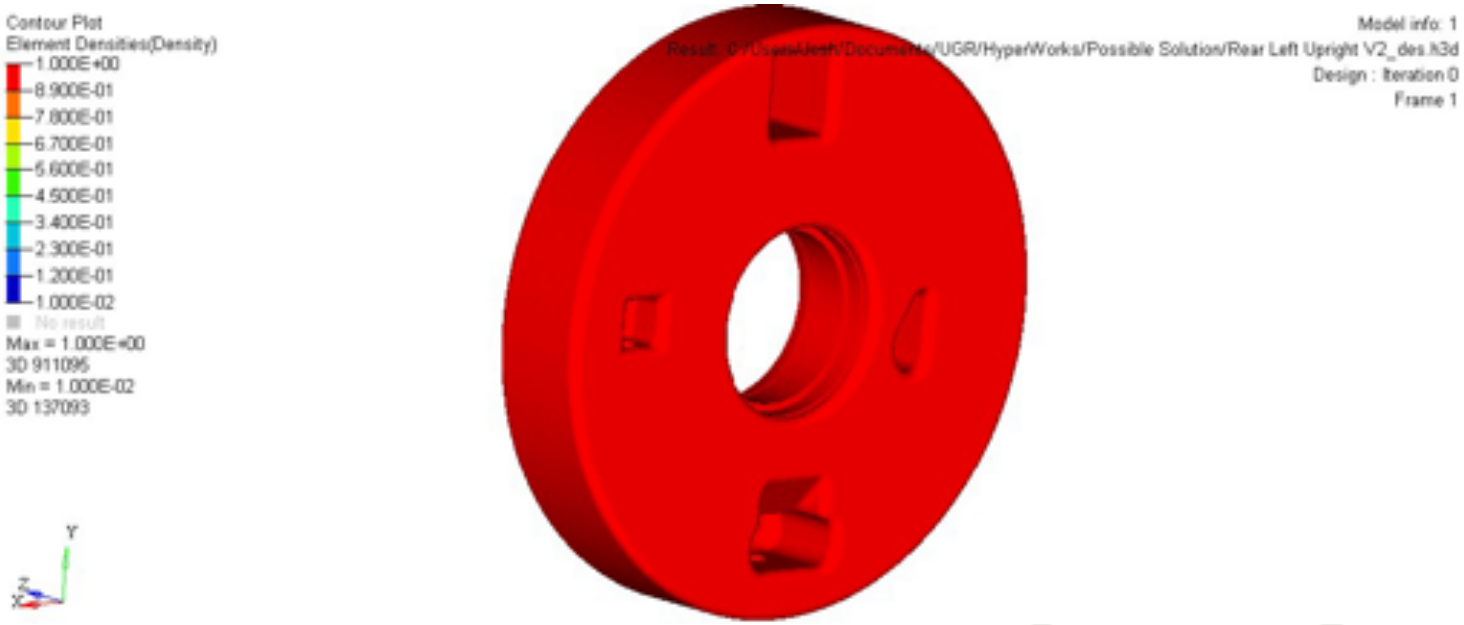
https://www.youtube.com/watch?v=6rBrm0o22l4

https://youtu.be/1GdCKdYk5ak

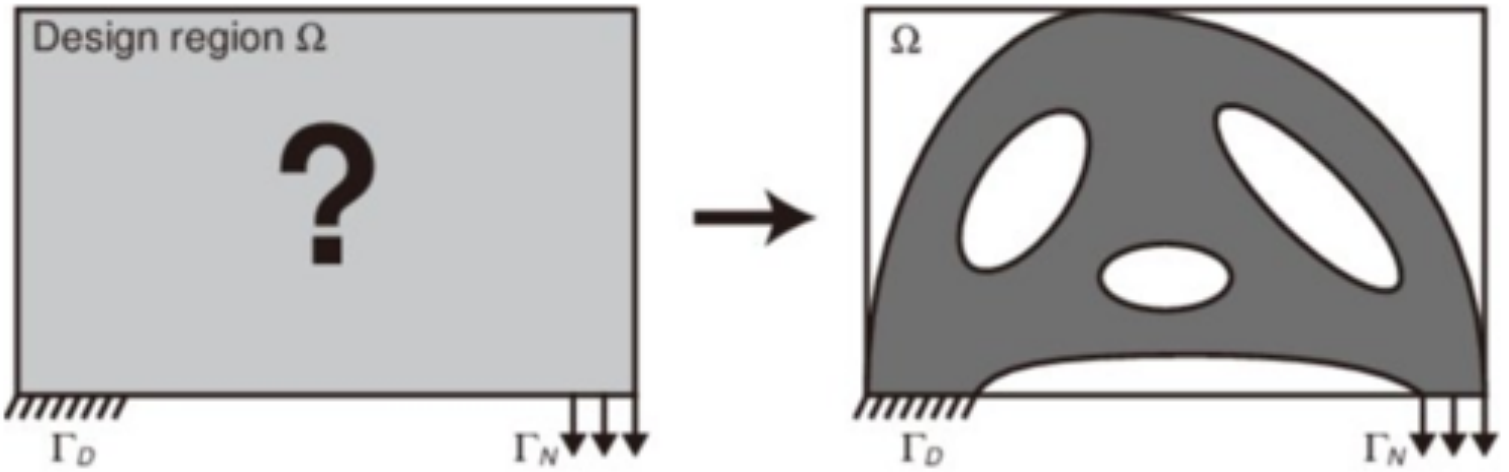


최적설계

Topology Optimization



최적설계 (Structural Optimization)



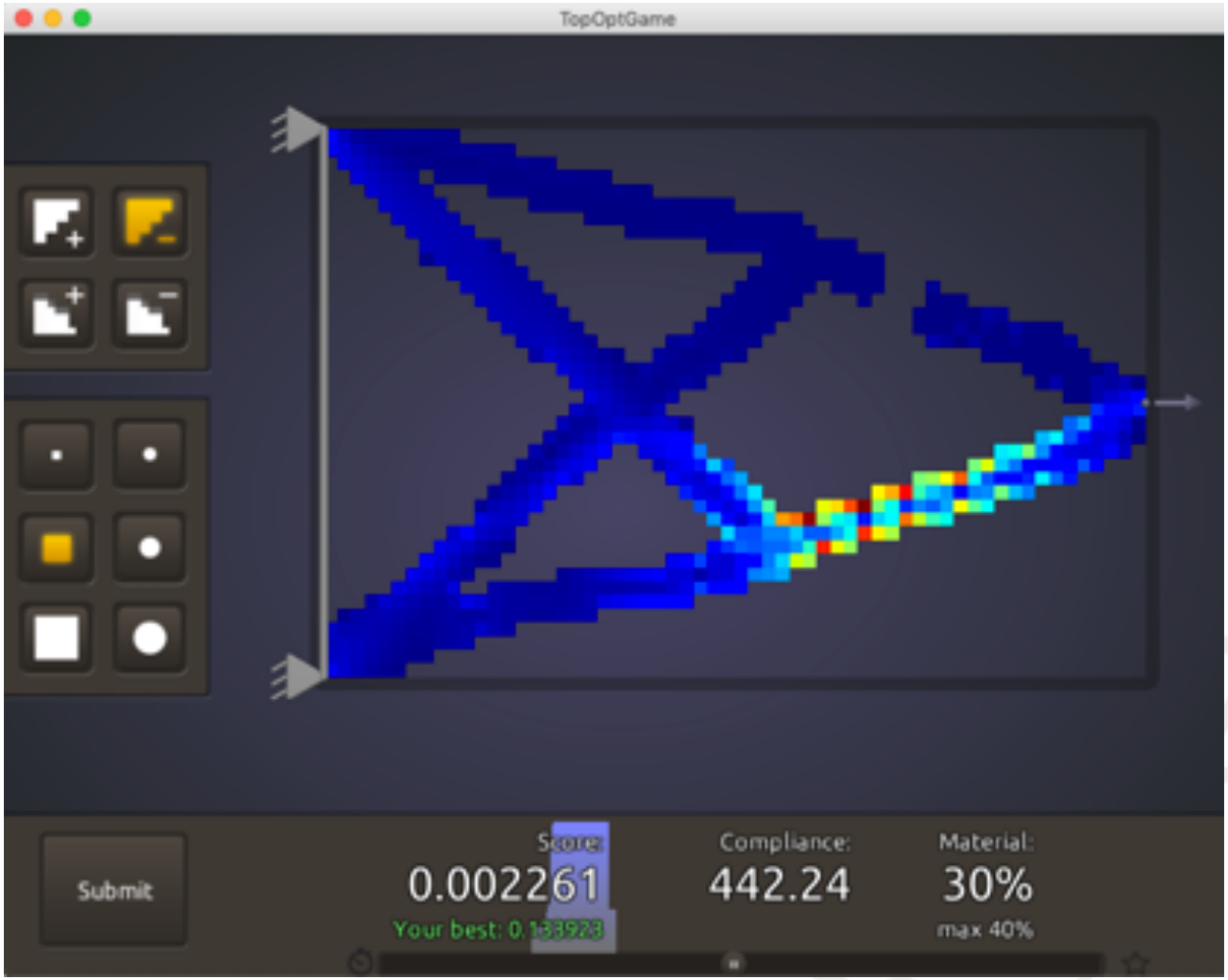
문제 정의 : 무엇을 어떤 목적으로 최적화 할 것인가?

- 무엇: 설계 대상, Domain, 경계조건
- 목적: 최적화 목적 (강성, 부피, 고유진동수, 음질…)

이슈 & 한계: 계산량, 제한적인 목적함수

Bi-directional Evolutionary Structural Optimization on Advanced Structures and Materials: A Comprehensive Review

TopOpt Game - be the optimizer




WORLD
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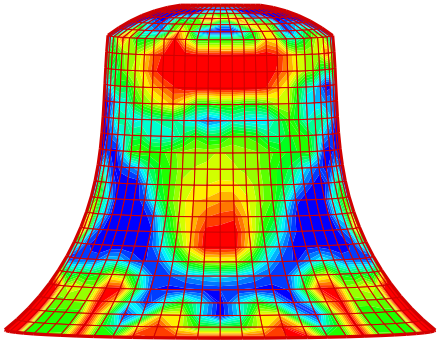
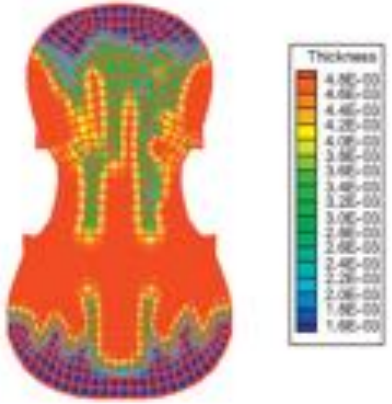
CLASSIC

Optimization of Musical Instruments: Examples

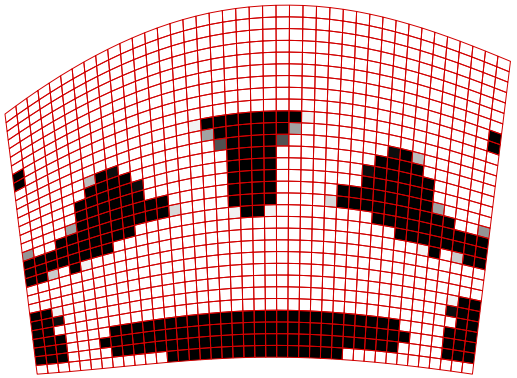
Musical bell [1]
(eigenvalue, radiation efficiency)



Violin plate [2]
(Shape of nodal line)

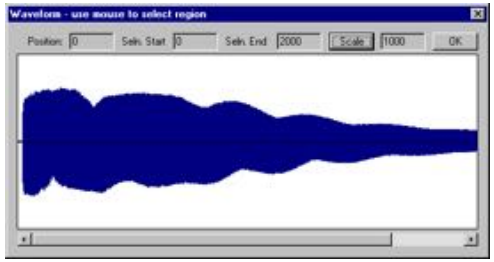


Violin bridge [3]
(Filtering characteristics)

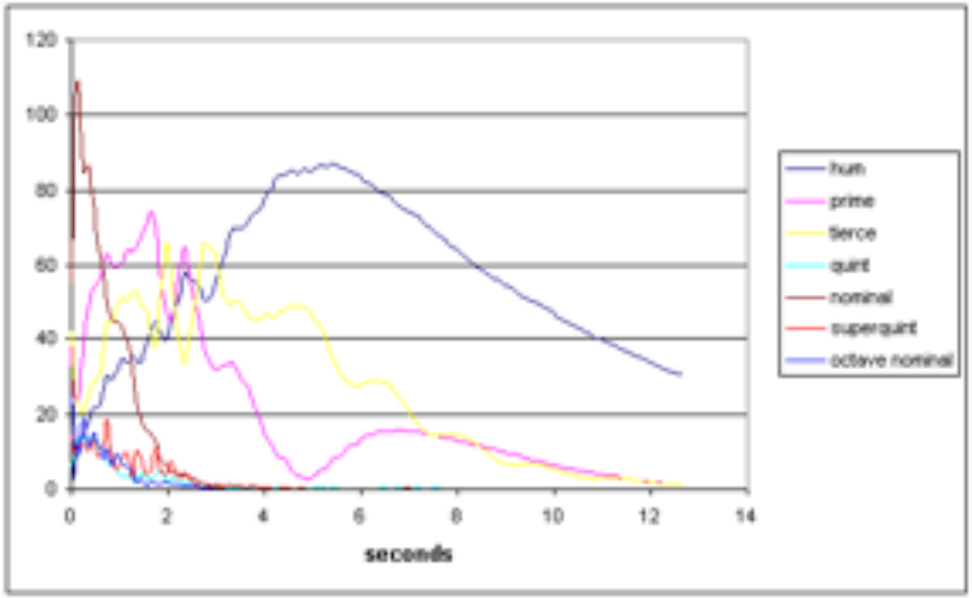


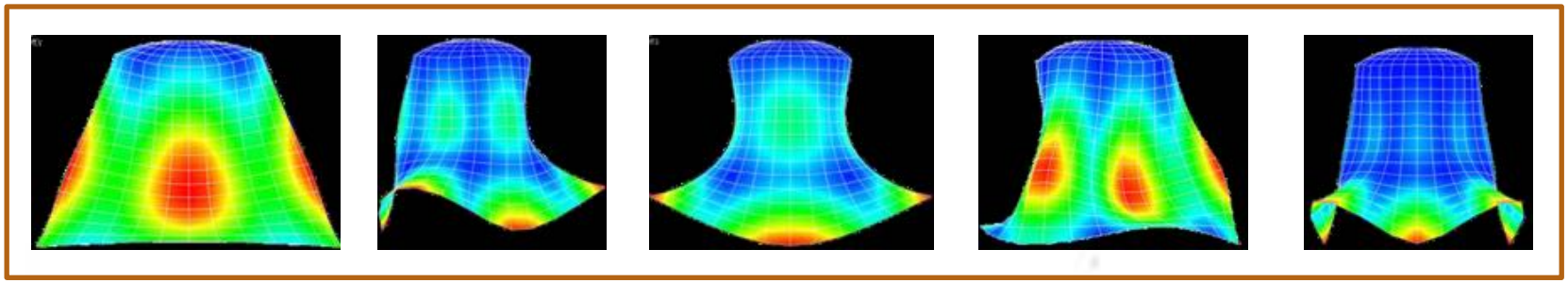
[1] Yu and Kwak, Design Sensitivity Analysis of Acoustic Damping and its Application to Design of Musical Bells Design, Structural Multidisciplinary Optimization, 2011
[2] Yu, Jang, Kim and Kwak, Nodal Line Optimization and its Application to Violin Top Plate Design, Journal of Sound and Vibration, 2010
[3] Yu and Kwak, Topology Optimization of Violin Bridges, Journal of Sound and Vibration, under review

Optimization of Musical Bells



- Characteristics of bell sounds
  - Frequencies of overtones(eigenvalue)
  - Acoustic damping (radiation eff.)

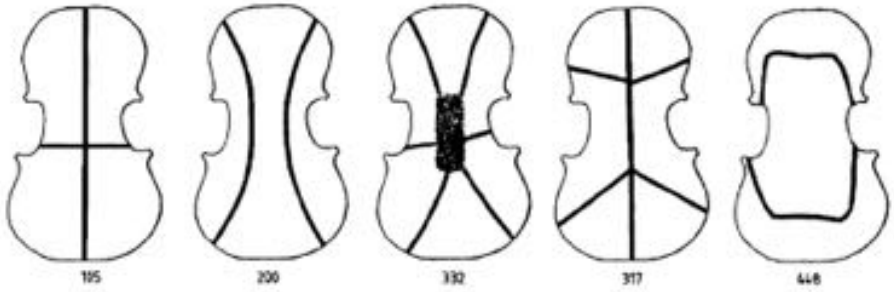




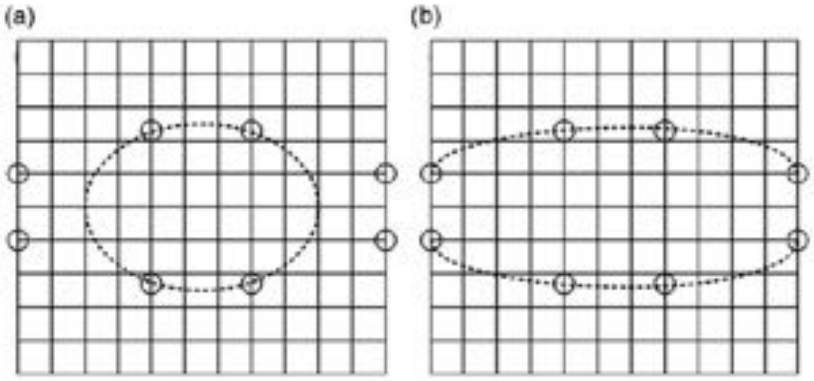
Eigenmodes

Optimization of violin plate (Nodal Line Optimization)

- Radiation efficiency
- Position of Nodes & antinodes



Nodal lines of violin plate (tuned)



$$\text{Minimize } \alpha \sum_{i=1}^{n_n} (w_2(\mathbf{x}_i))^2 + (1-\alpha) \sum_{i=1}^{n_n} (w_5(\mathbf{x}_i))^2$$

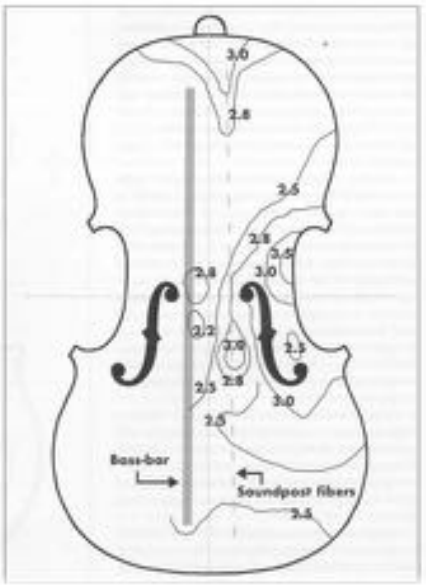
$$170(\text{Hz}) \le \lambda_2 \le 230(\text{Hz})$$

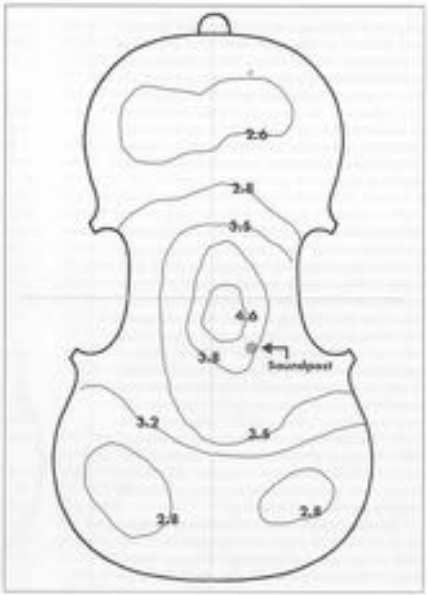
$$370(\text{Hz}) \le \lambda_5 \le 430(\text{Hz})$$

$$1.5(\text{mm}) \le t_m \le 5.0(\text{mm}), \quad m = 1,2,\ldots,n_e$$

Target node

Nodal line





Thickness distribution of violin plate

Optimization of violin plate (Nodal Line Optimization)

$$\text{Minimize } \alpha \sum_{i=1}^{n_n} (w_2(\mathbf{x}_i))^2 + (1-\alpha) \sum_{i=1}^{n_n} (w_5(\mathbf{x}_i))^2$$

$$170(\text{Hz}) \le \lambda_2 \le 230(\text{Hz})$$

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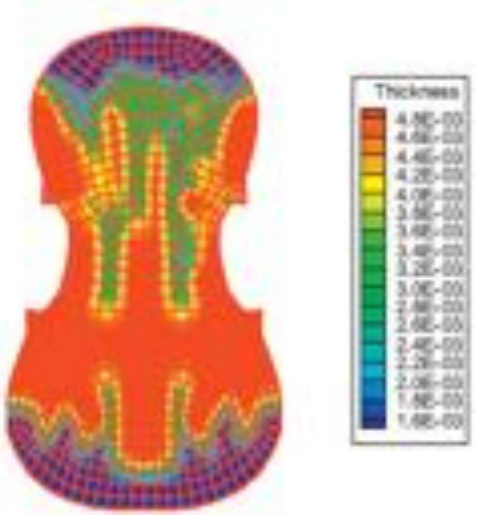
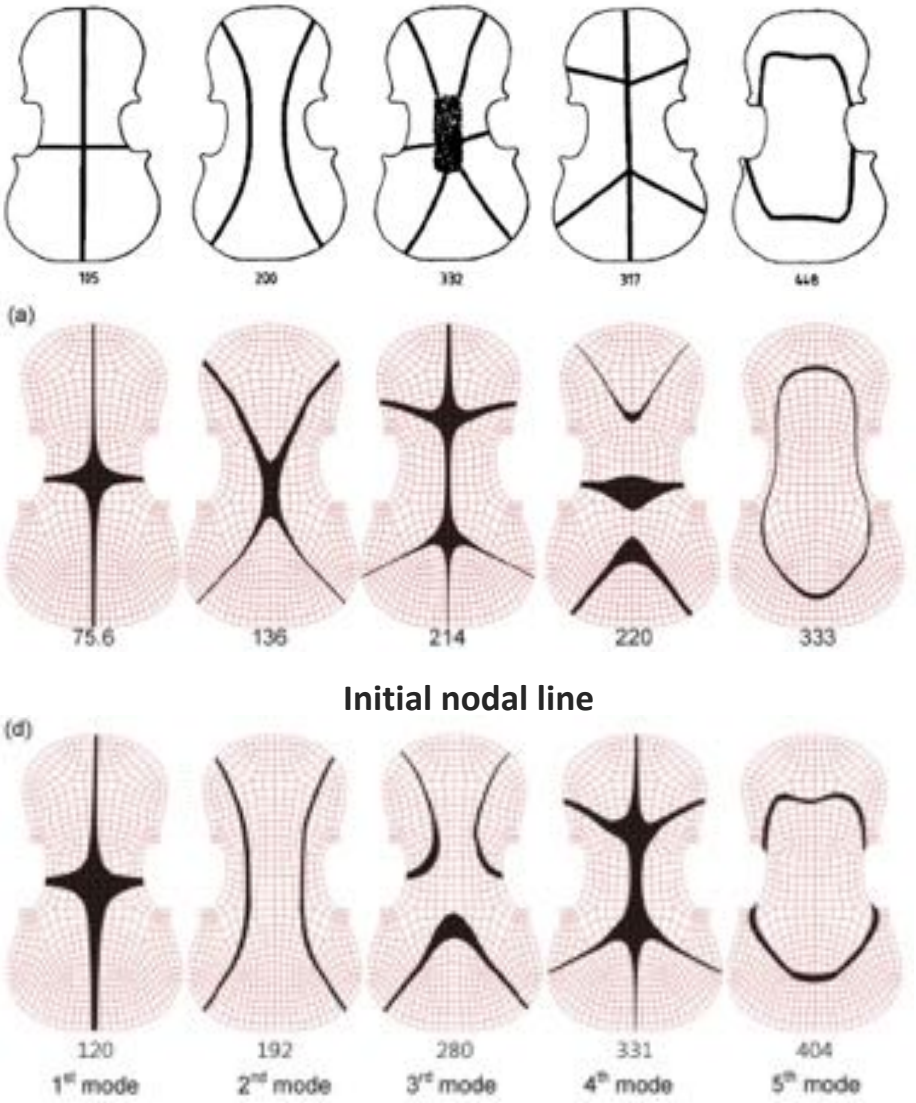




Initial nodal line

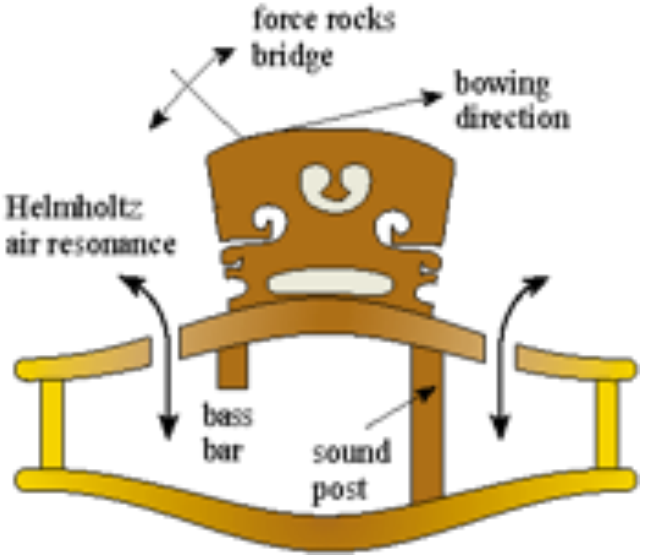
Optimized nodal line

Topology Optimization of Violin Bridge

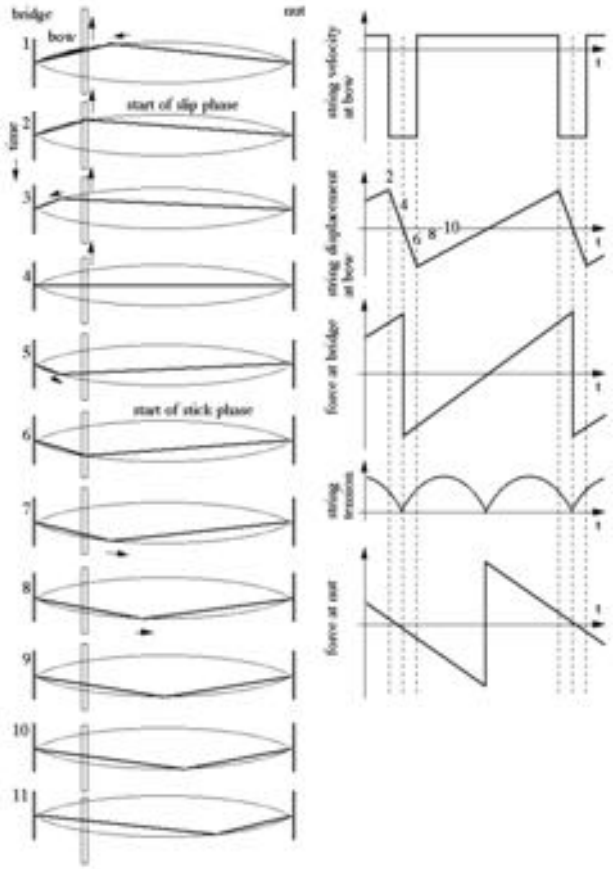
» Transfer
- **transverse force** from string into **normal force** to violin body

» Hold & Keep
- strings from violin body

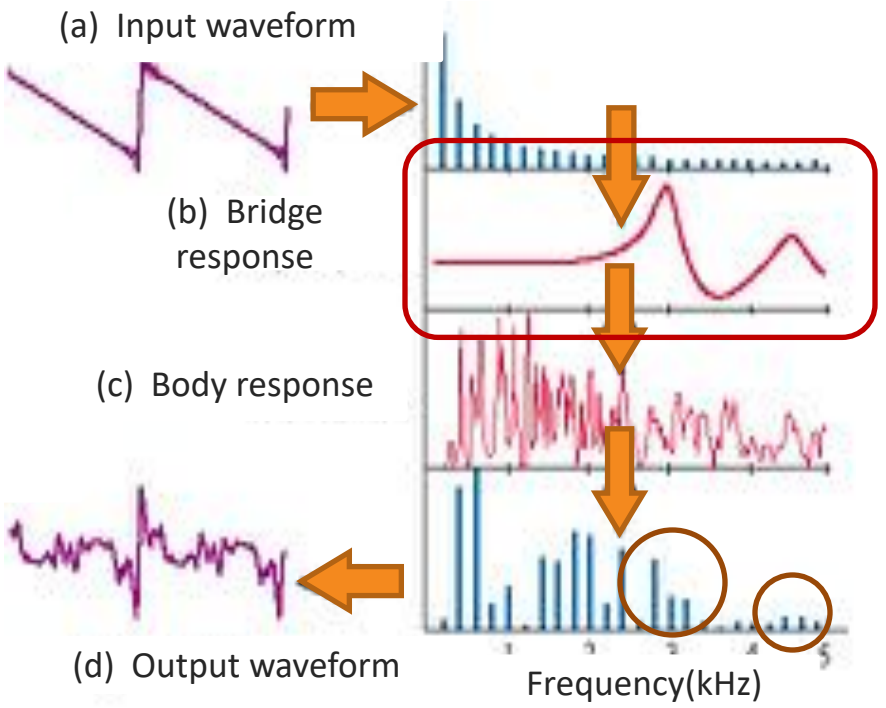
» Important part for tuning violin
- balance **spectral envelope**
- **Replaceable part**



Generation of Violin Sound



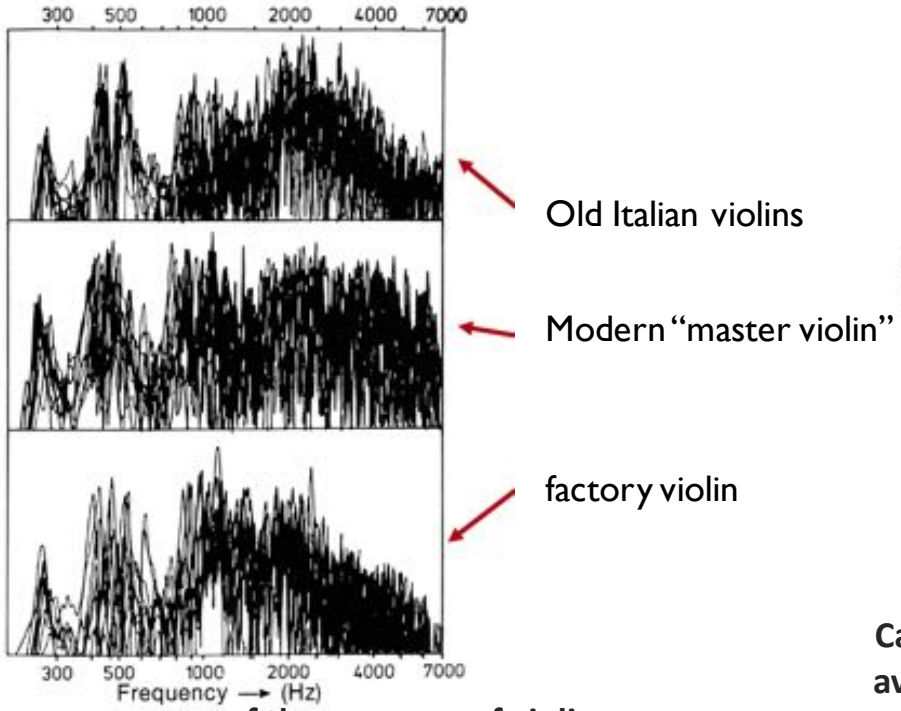
Idealized bowed string motion



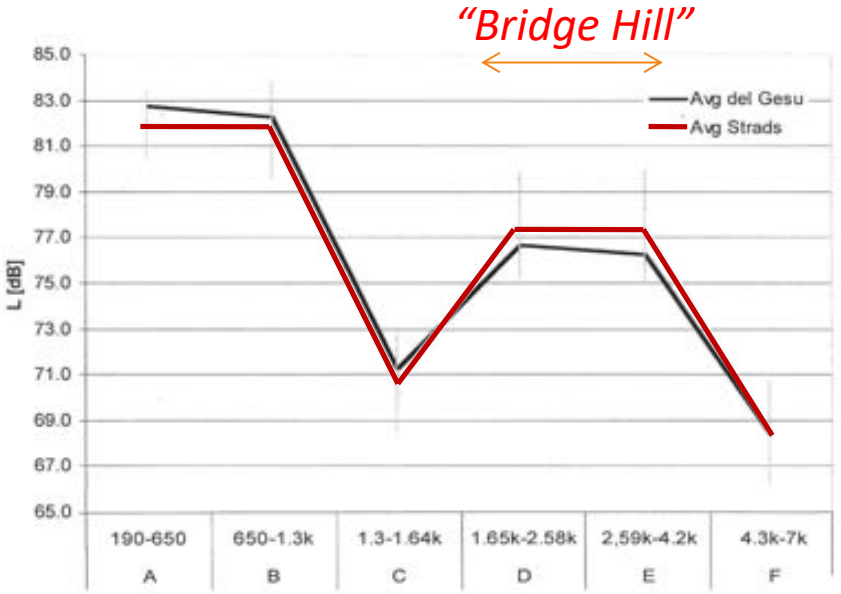
The relationship between the input waveform of the violin and the output waveform

Dunnwald Frequency Band for Violin Timbre

Timbre parameter	Definition	Comment
Bass	A - B	High values for good and bass-rich violins
Nasality	ACD – B	High value for 'non nasal' violins; lo w values for 'nasal' violin
Clarity	DE - F	High values for 'clear' violins; Violins with low values sound 'harsh'

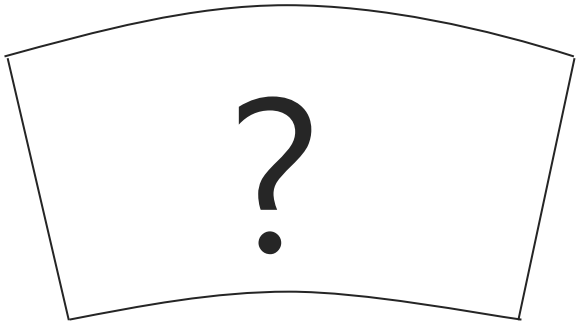


Response curves of three groups of violins.



Calculated levels of each Dunnwald frequency band for the average LTAS produced by 15 violins by A. Stradivari and 15 violins by G. Guarneri del Gesu. (Buen, 2007)

Motivation



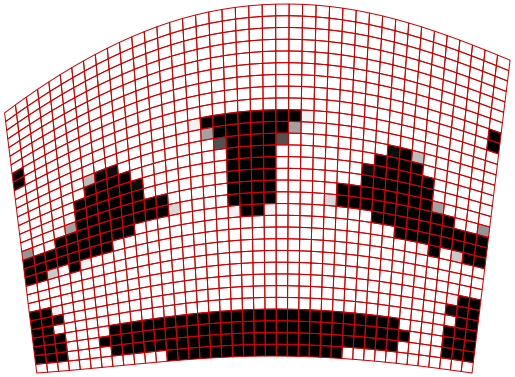
- Mechanical filter, transmitter or resonator
- What is the optimal structure?

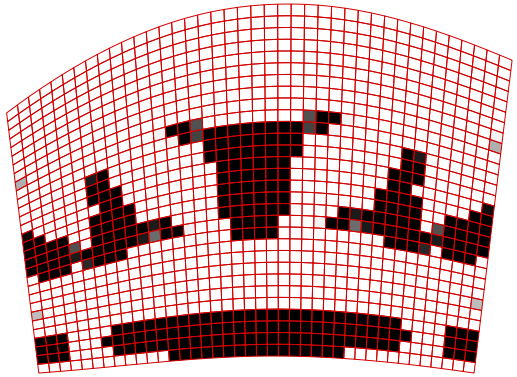
Topology optimization technique is applied.

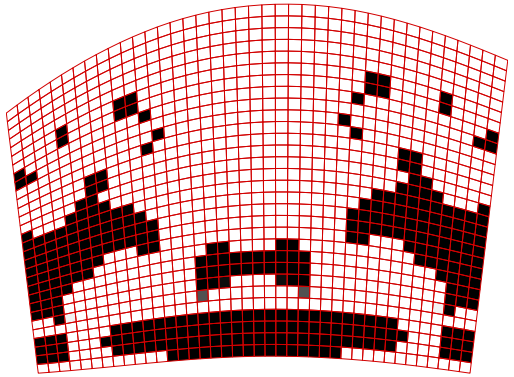
Results

Maximize

Bridge Hill | **1st In-plane resonance** | **Bass**







Modern bridge

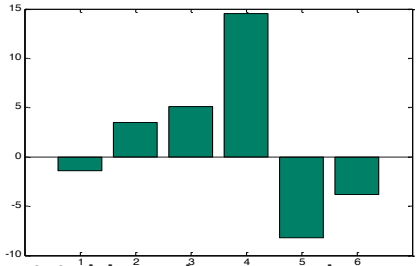
Baroque Bridge

Tuning Violin Sound with Optimized Violin Bridge

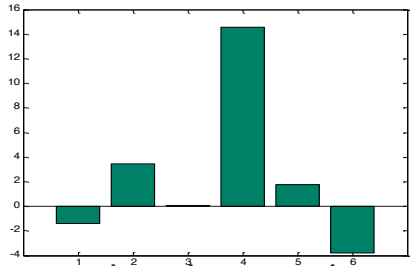
recording → Input Wav File → wavread() → Input Signal → Fourier transform(fft()) → Partial Strength → Band - Averaged Strength

Parameter Tuning

playing ← Output Wav File ← wavwrite() ← Output Signal ← Inverse Fourier transform(ifft()) ← Tuned Partial Strength ← Band-Averaged Strength



Initial band strength



Target band strength

악기연구소의 꿈

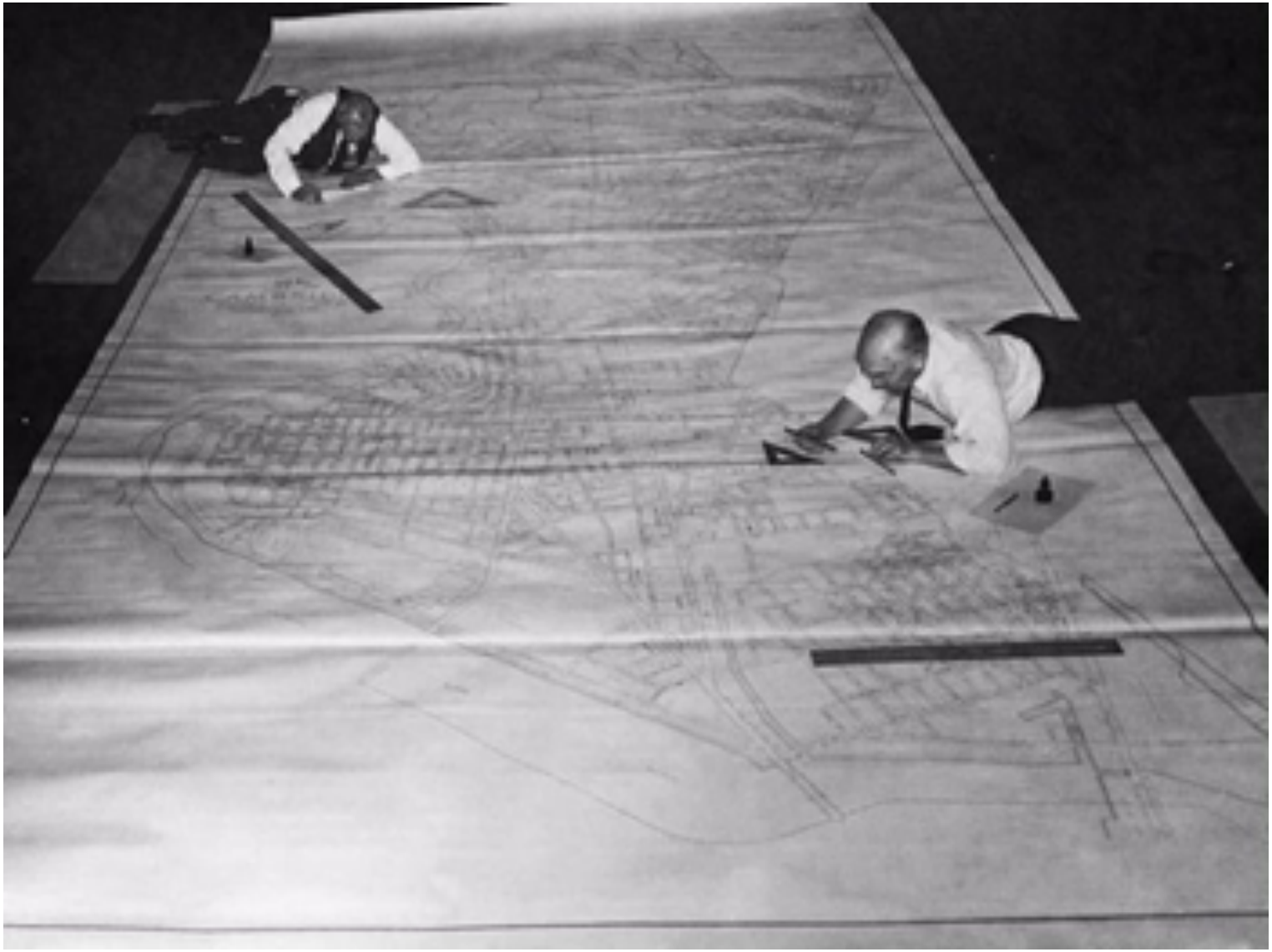
Martin Schleske

국악기 세계화!



원자력연구원

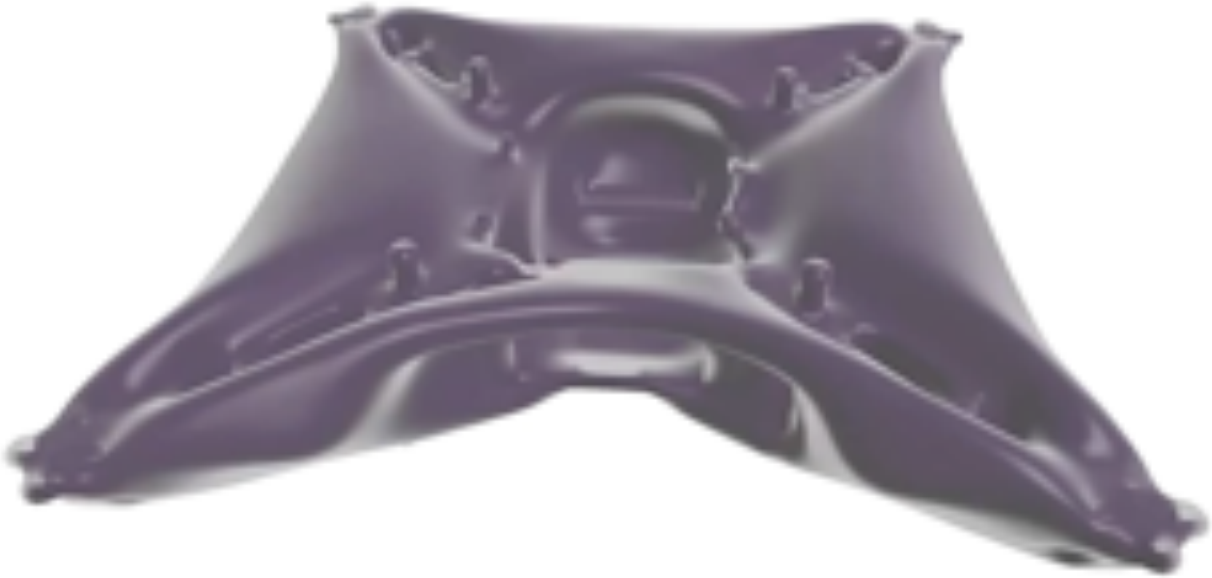
현실....



2016.3.15

2017.5.17

Autodesk Generative Design



AUTODESK

Autodesk Generative Design

위상최적설계 결과물

Topology optimization methods

SIMP

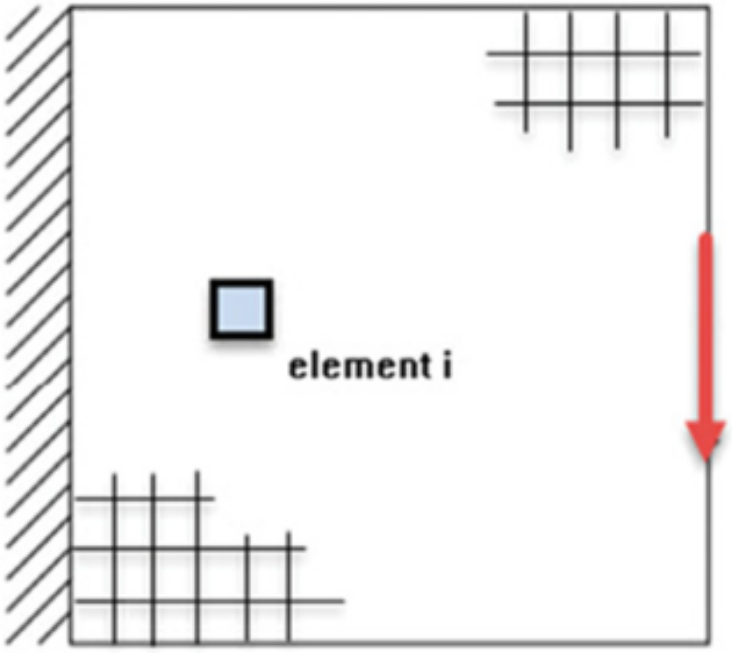
**solid isotropic microstructure with penalization

ESO

*evolutionary structural optimization

SIMP (solid isotropic microstructure with penalization)

$$\begin{aligned} \underset{x}{\text{minimize}} \quad & F = F(\mathbf{u}(\rho), \rho) = \int_\Omega f(\mathbf{u}(\rho), \rho) \mathrm{d}V \\ \text{subject to} \quad & G_0(\rho) = \int_\Omega \rho \mathrm{d}V - V_0 \leq 0 \\ & G_j(\mathbf{u}(\rho), \rho) \leq 0 \text{ with } j = 1, \ldots, m \end{aligned}$$



$$\frac{dF}{d\rho} = ?$$

Augmented objective function: $\hat{\Phi} = \Phi + \lambda^T (KU - F)$

Differentiate: $\hat{\Phi}' = \frac{\partial \Phi}{\partial U} U' + \lambda^T \left(K'U + KU' \right)$

Collect U' terms: $\left(\lambda^T K + \frac{\partial \hat{\Phi}}{\partial U} \right) U' = 0 \Rightarrow \lambda^T K + \frac{\partial \hat{\Phi}}{\partial U} = 0$

Adjoint problem: $K^T \lambda = - \left(\frac{\partial \hat{\Phi}}{\partial U} \right)^T \Rightarrow$

Final sensitivity: $\hat{\Phi}' = \lambda^T K' U$

https://mavt.ethz.ch/content/dam/ethz/special-interest/mavt/department-dam/news/documents/sigmund-presentation-dls-hs-15.pdf

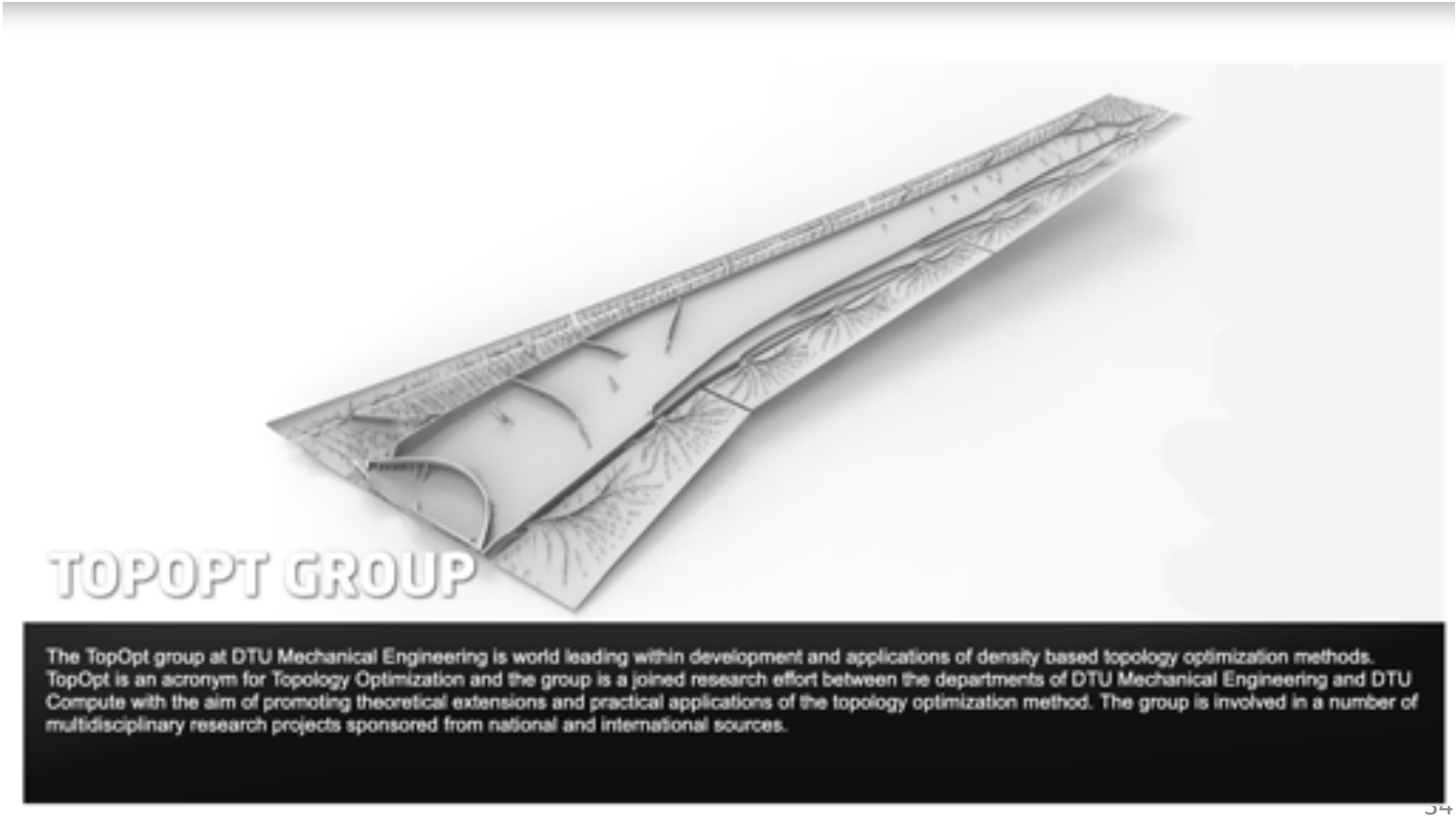
nature
International journal of science

Letter | Published: 04 October 2017

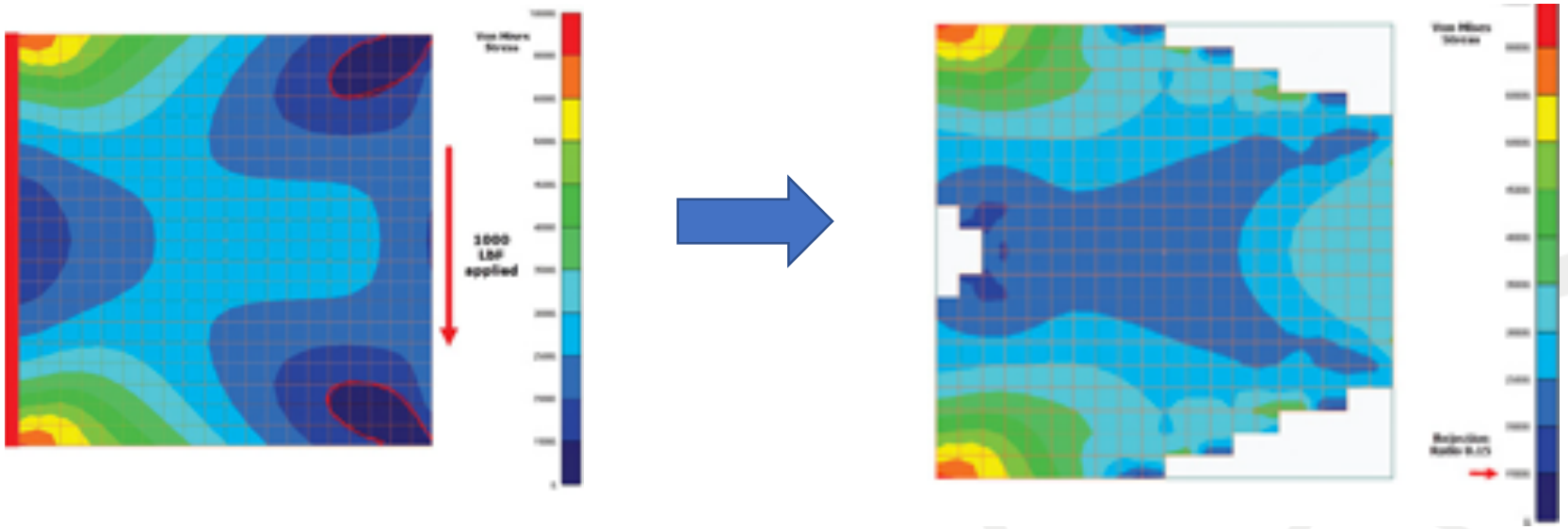
10억?!

Giga-voxel computational morphogenesis for structural design

Niels Aage ✉, Erik Andreassen, Boyan S. Lazarov & Ole Sigmund



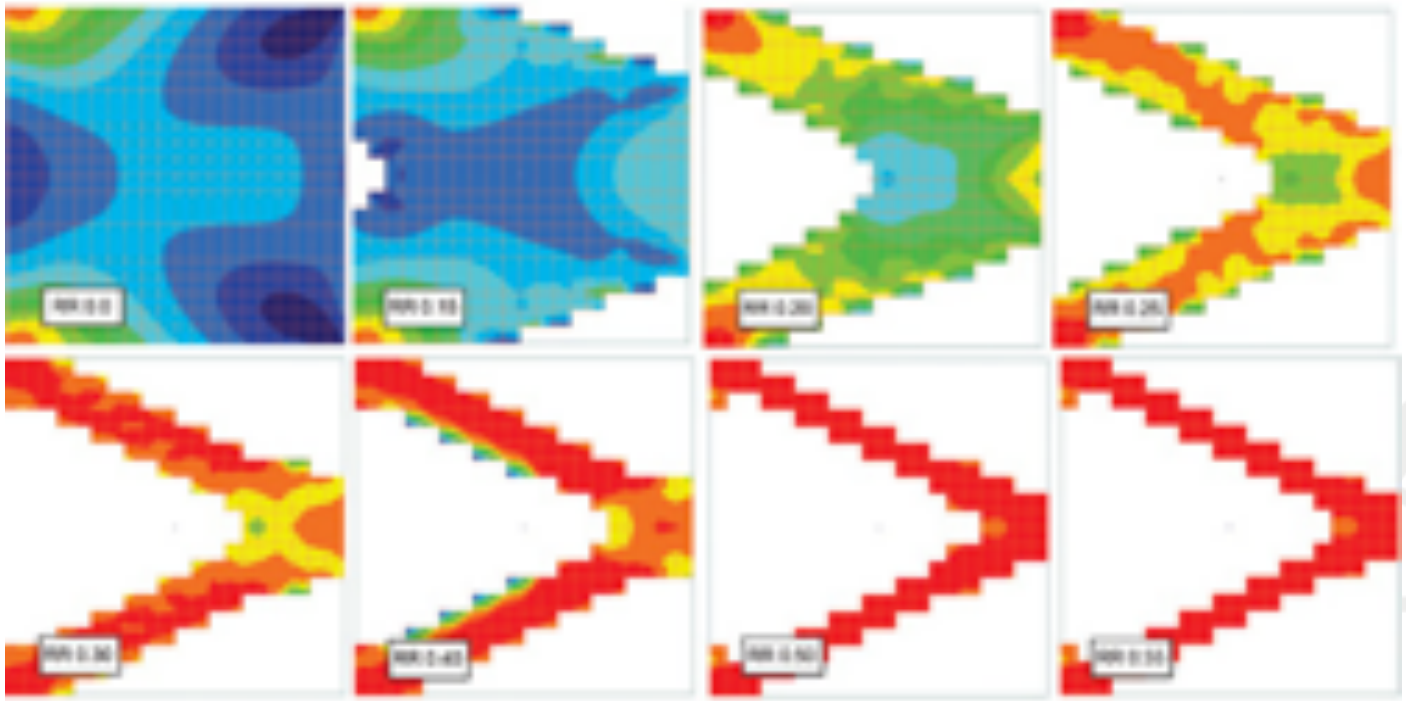
ESO (evolutionary structural optimization)



응력이 낮은 20% 물질을 제거하라!

https://www.digitalengineering247.com/article/topology-optimization-methods/

ESO



SIMP vs. ESO

Brief note

Struct Multidisc Optim 21, 80–83

On the validity of ESO type methods in topology optimization

M. Zhou and G.I.N. Rozvany

Abstract It is shown on a simple test example that ESO's rejection criteria may result in a highly nonoptimal design. Reasons for this failure are also discussed.

It is shown in this note on a simple example that (a) ESO's rejection criteria may result in an extremely nonoptimal design and (b) BESO is unable to reverse this failure.

Structural and Multidisciplinary Optimization
May 2010, Volume 41, Issue 5, pp 671–683 | Cite as

A further review of ESO type methods for topology optimization

Authors | Authors and affiliations

Xiaodong Huang ✉, Yi-Min Xie

Forum Discussion
First Online: 06 March 2010

Abstract

Evolutionary Structural Optimization (ESO) and its later version bi-directional ESO (BESO) have gained widespread popularity among researchers in structural optimization and practitioners in engineering and architecture. However, there have also been many critical comments on various aspects of ESO/BESO. To address those criticisms, we have carried out extensive work to improve the original ESO/BESO algorithms in recent years. This paper summarizes latest developments in BESO for stiffness optimization problems and compares BESO with other well-established optimization methods. Through a series of numerical examples, this paper provides answers to those critical comments and shows the validity and

위상최적설계에서 기계학습

SIMP

ESO

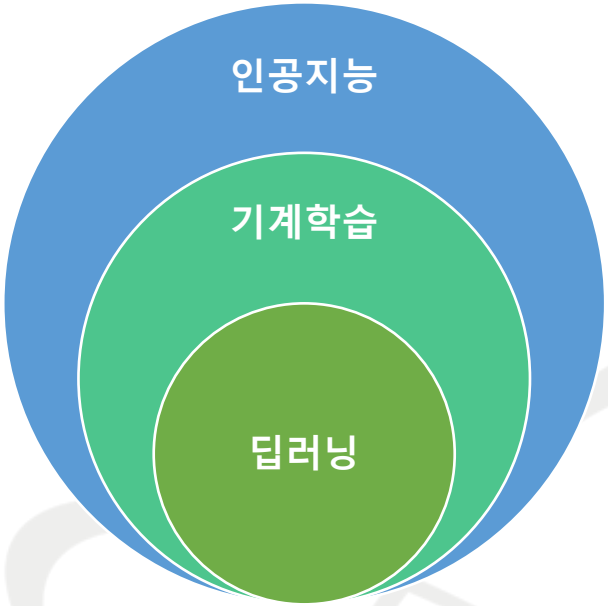
ML

기계학습(Machine Learning)

특정한 과제에 대해서

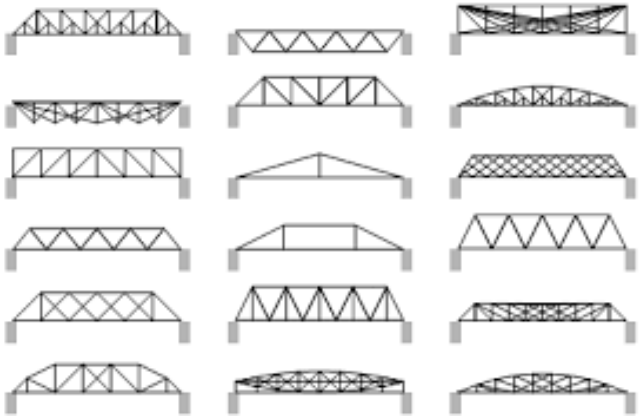
경험을 통해

성능을 향상시키는 것

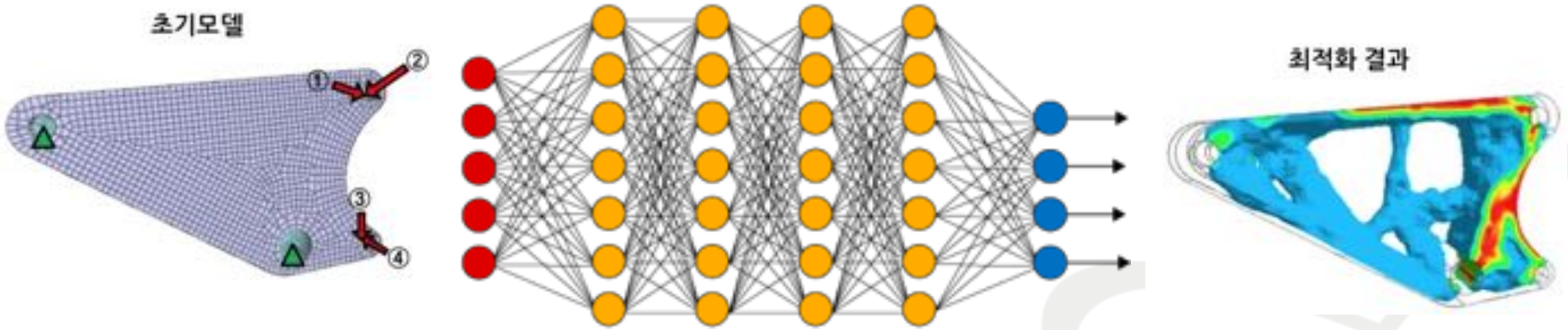


경험을 통해 데이터를 모아서
패턴을 분석해서 성능을 향상시키는 것

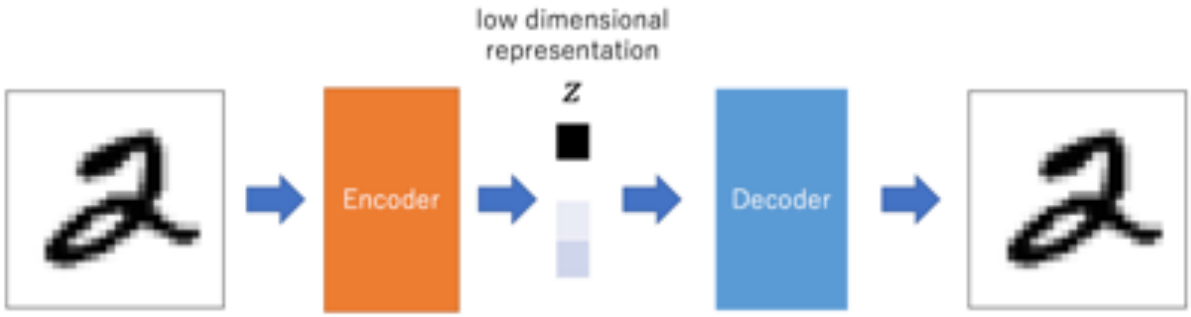
기존 설계로부터 설계의 원리를 배운다면?

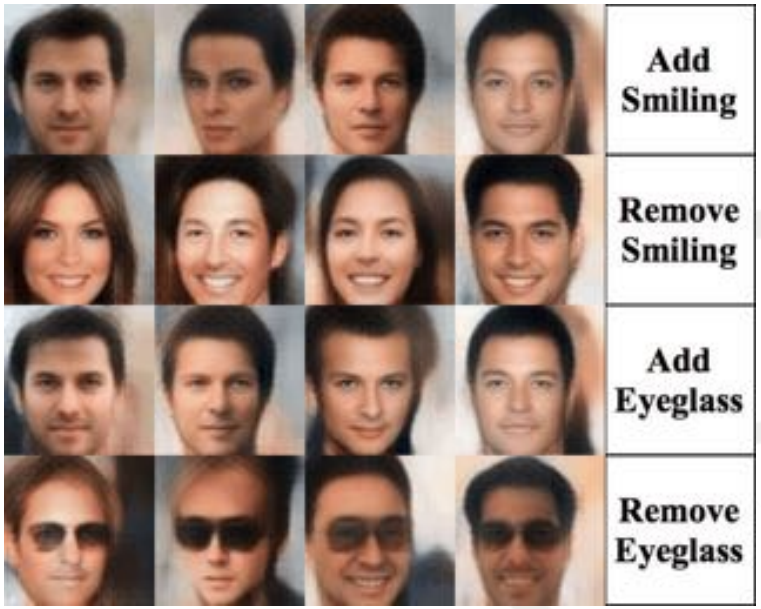


AI가 최적설계를 대신해줄 수 없을까?



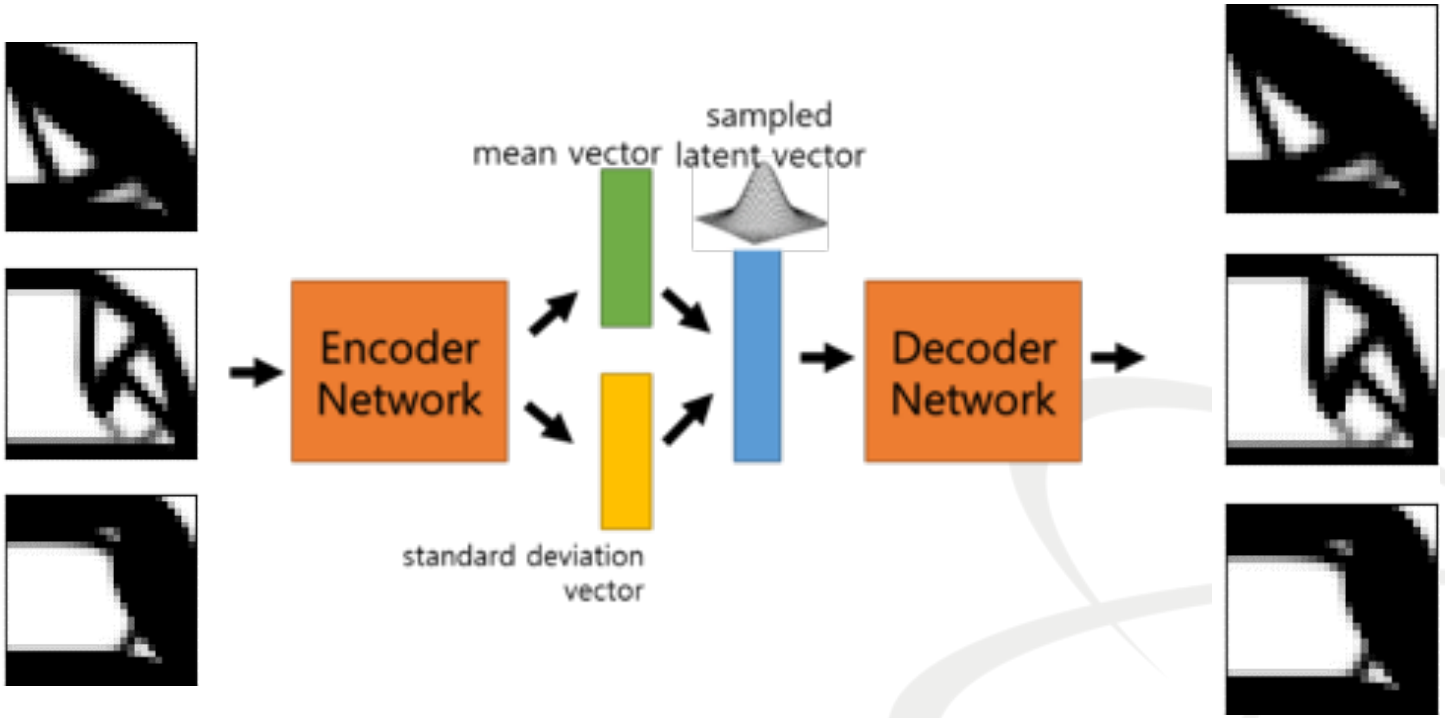
Variational Autoencoder



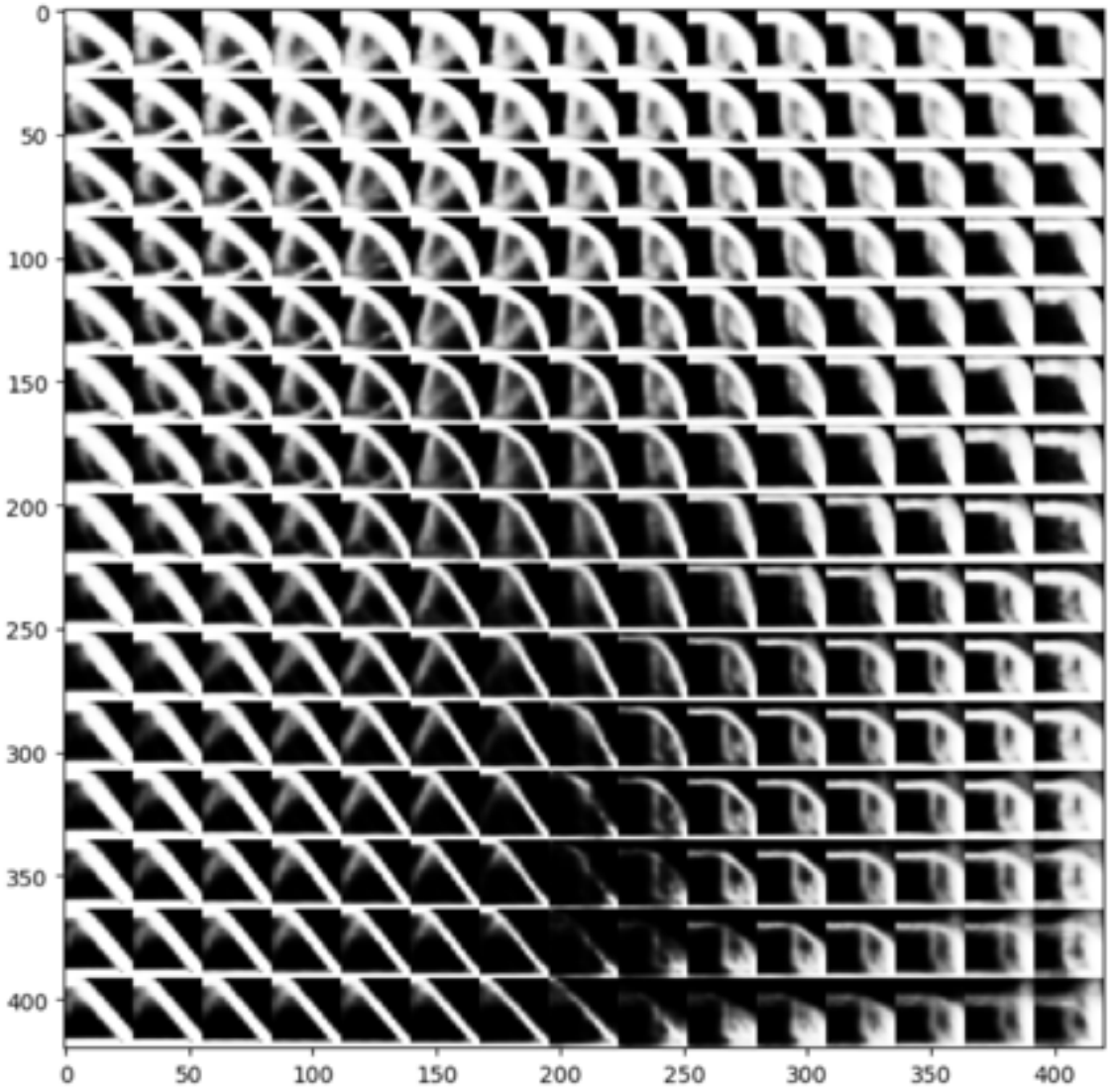


Unsupervised Learning of Topology Optimization Results

가능한 적은 수의 변수로 구조를 표현할 수 있는가?



2개의 잠재변수로 표현한 구조



Deep Learning for Topology Optimization Design

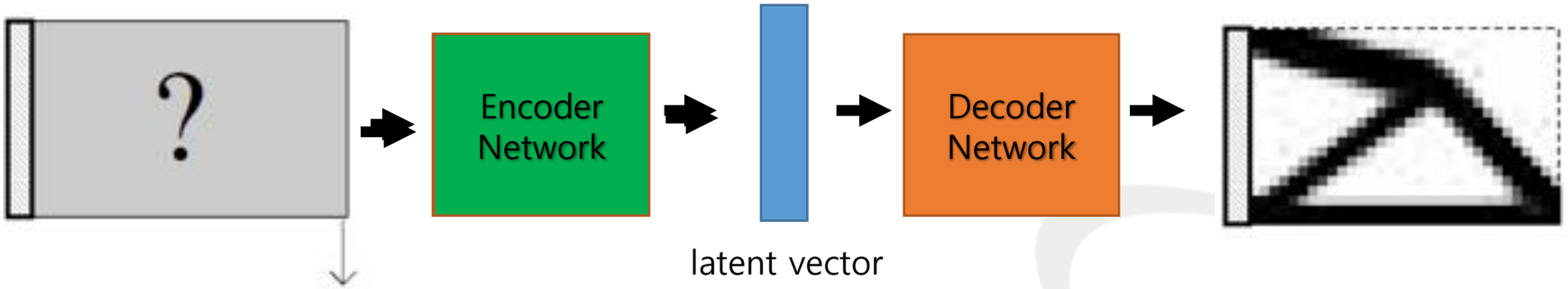
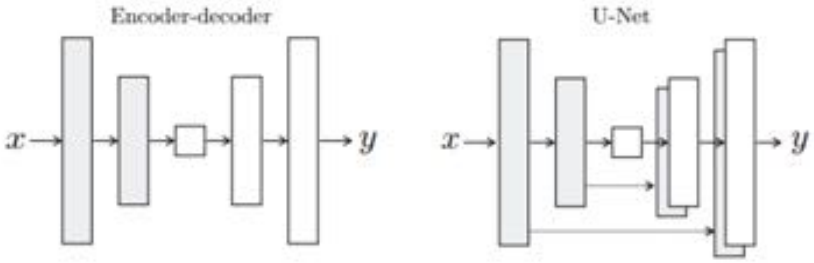
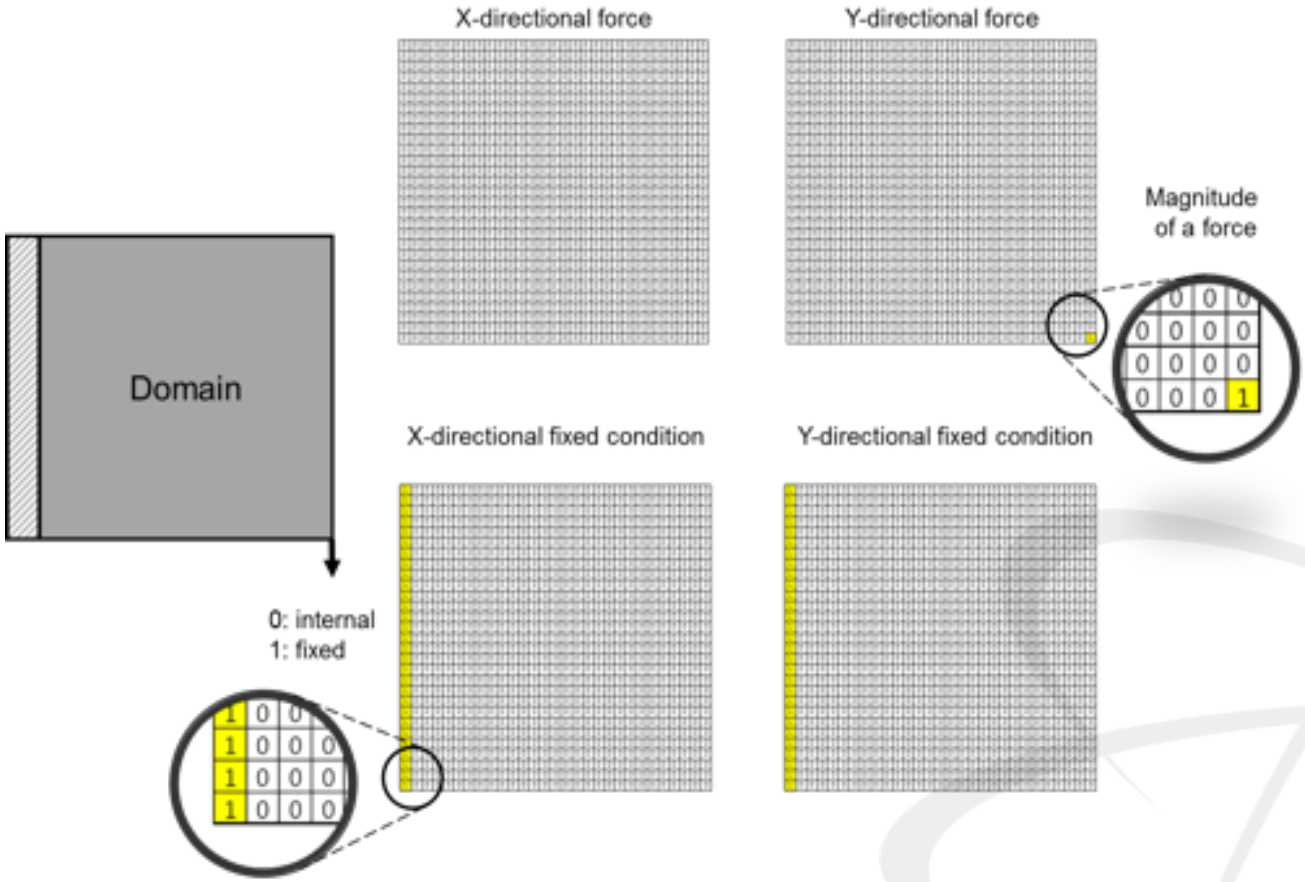


Image-to-Image Translation with Conditional Adversarial Networks

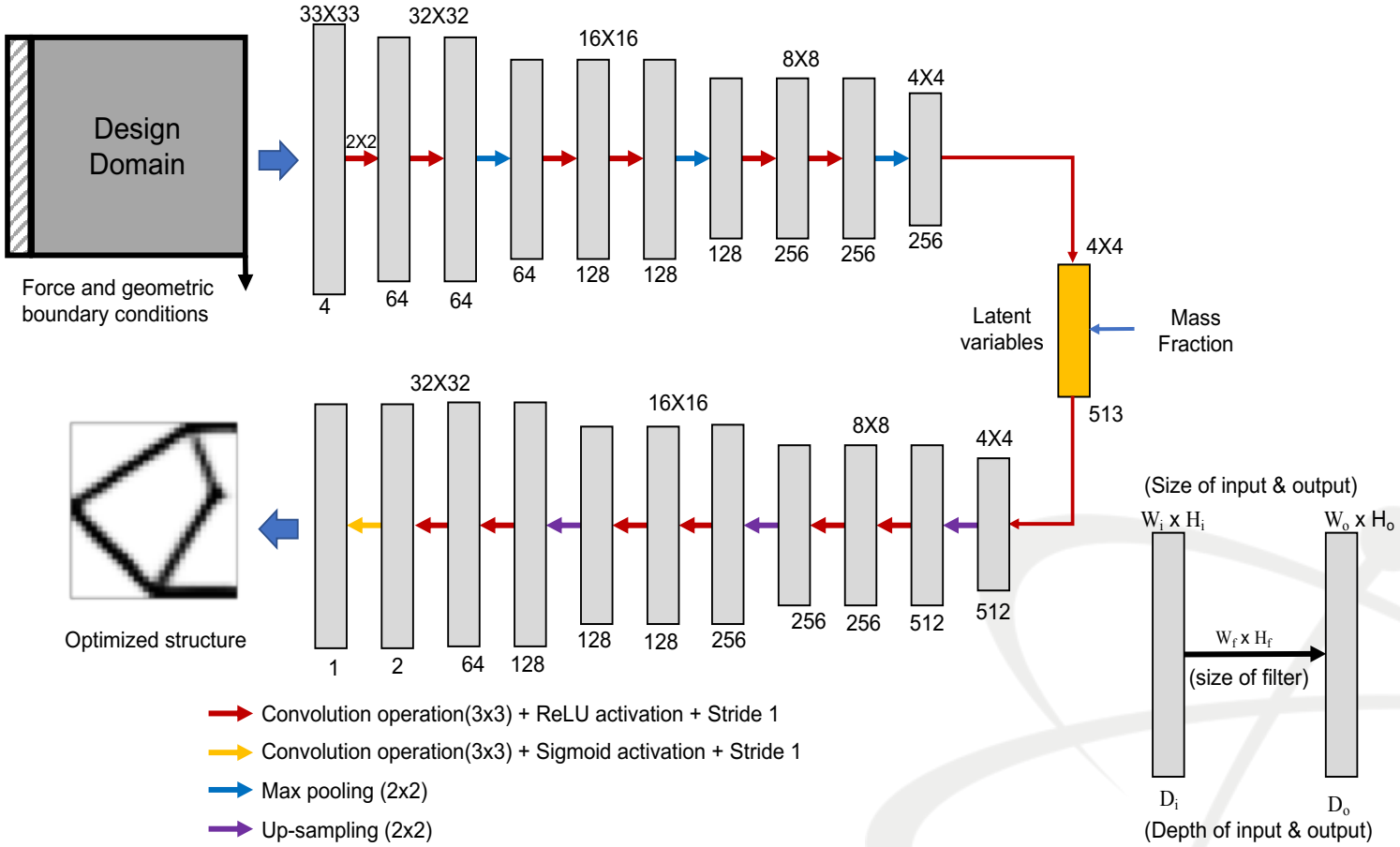


Deep Learning for Topology Optimization Design : Discretization of boundary conditions



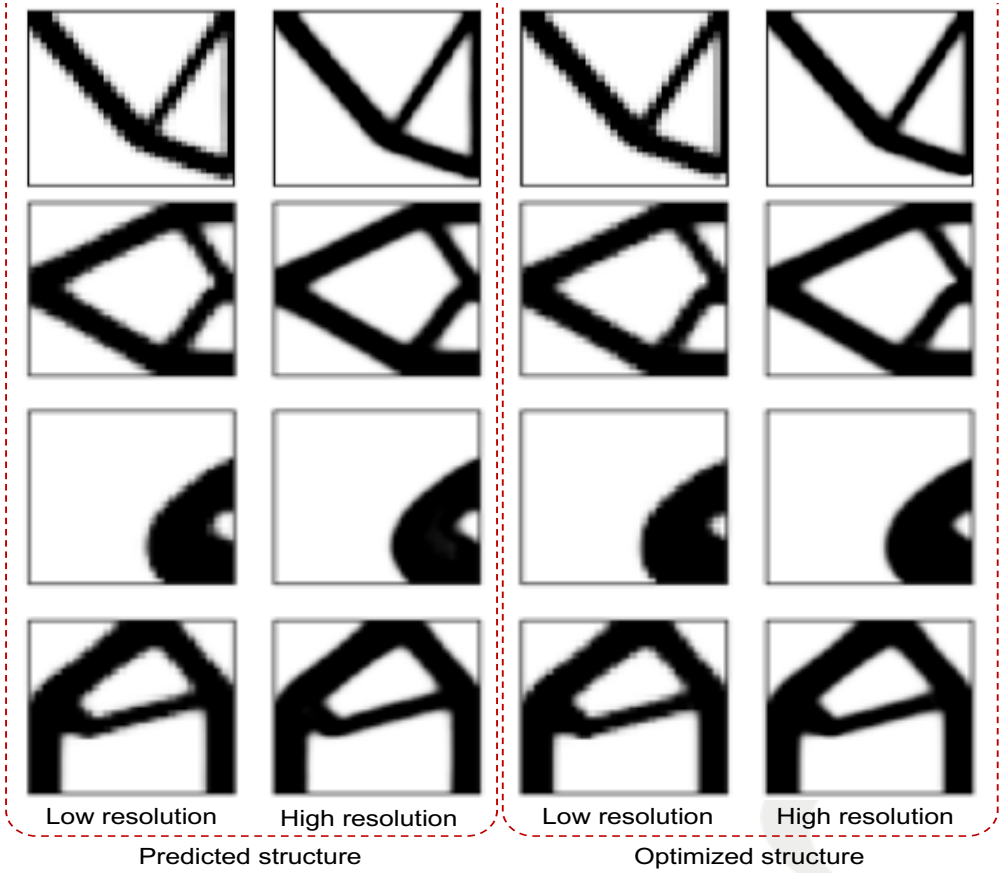
https://arxiv.org/abs/1801.05463

Deep Learning for Topology Optimization Design : 1st Stage



https://arxiv.org/abs/1801.05463

Deep Learning for Topology Optimization Design



https://arxiv.org/abs/1801.05463

Structural and Multidisciplinary Optimization
https://doi.org/10.1007/s00158-018-2101-5

RESEARCH PAPER

Deep learning for determining a near-optimal topological design without any iteration

Yonggyun Yu[1] · Taeil Hur[2] · Jaeho Jung[1] · In Gwun Jang[3]

Received: 3 December 2017 / Revised: 17 August 2018 / Accepted: 17 September 2018

Abstract
In this study, we propose a novel deep learning-based method to predict an optimized structure for a given boundary condition and optimization setting without using any iterative scheme. For this purpose, first, using open-source topology optimization code, datasets of the optimized structures paired with the corresponding information on boundary conditions and optimization settings are generated at low (32 × 32) and high (128 × 128) resolutions. To construct the artificial neural network for the proposed method, a convolutional neural network (CNN)-based encoder and decoder network is trained using the training dataset generated at low resolution. Then, as a two-stage refinement, the conditional generative adversarial network (cGAN) is trained with the optimized structures paired at both low and high resolutions and is connected to the trained CNN-based encoder and decoder network. The performance evaluation results of the integrated network demonstrate that the proposed method can determine a near-optimal structure in terms of pixel values and compliance with negligible computational time.

Keywords Deep learning · Machine learning · Topology optimization · Generative model · Generative adversarial network · Convolutional neural network

3차원도 해야하고..

BC를 더 일반화 해야하고..

설계 Domain이 변했을 때 어떻게 처리해야하나..

근처는 잘 찾는데 Optimum은 아니고...

...

..

....

기존 방법론과 융합할 수 있는 방법은 없을까?

정해진 Domain 만 잘 풀어도 되는 문제가 없을까?

임의의 Domain 문제로 확장할 수 있지 않을까?


SIMP
ESO
AI

경험(과거 해석 데이터)를 통하여

우리가 몰랐던 패턴을 발견하여

기존 알고리즘을 점점 발전시킬 수 있지 않을까?

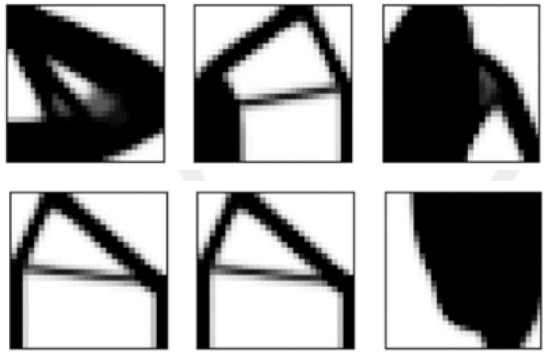
SIMP + ML ?

Optimization Scheduler

기존 최적설계

$$\frac{\partial c}{\partial x_e} = -p(x_e)^{p-1}\ \mathbf{u}_e^T\ \mathbf{k}_0\ \mathbf{u}_e$$

머신러닝 알고리즘



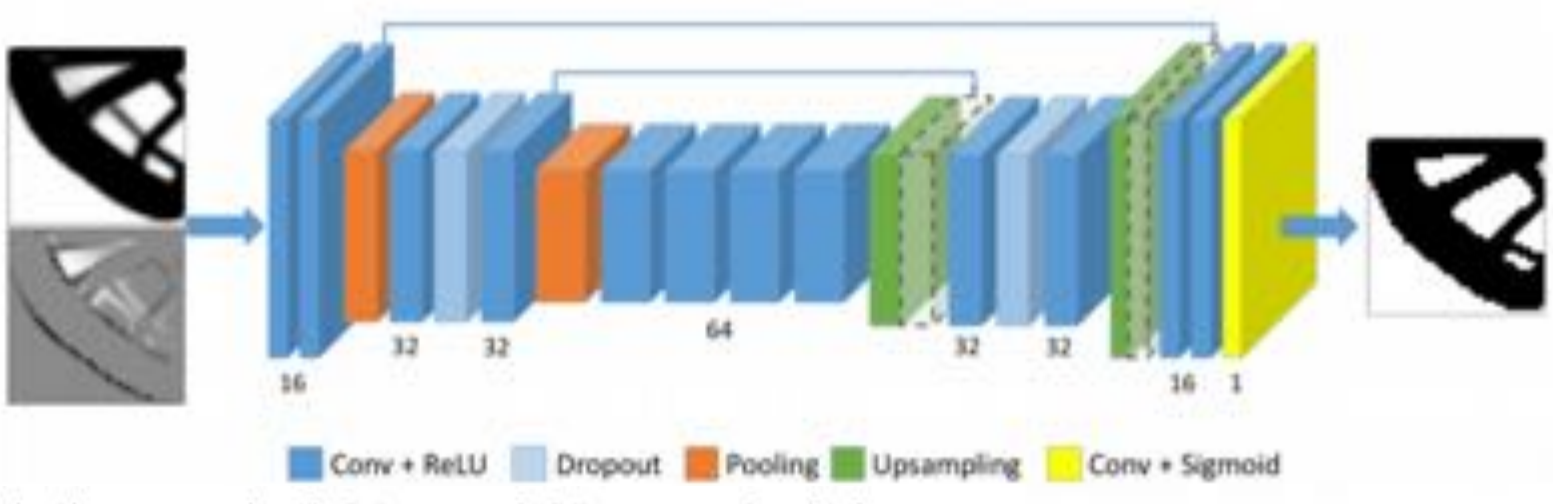
위상최적설계 (Topology Optimization)

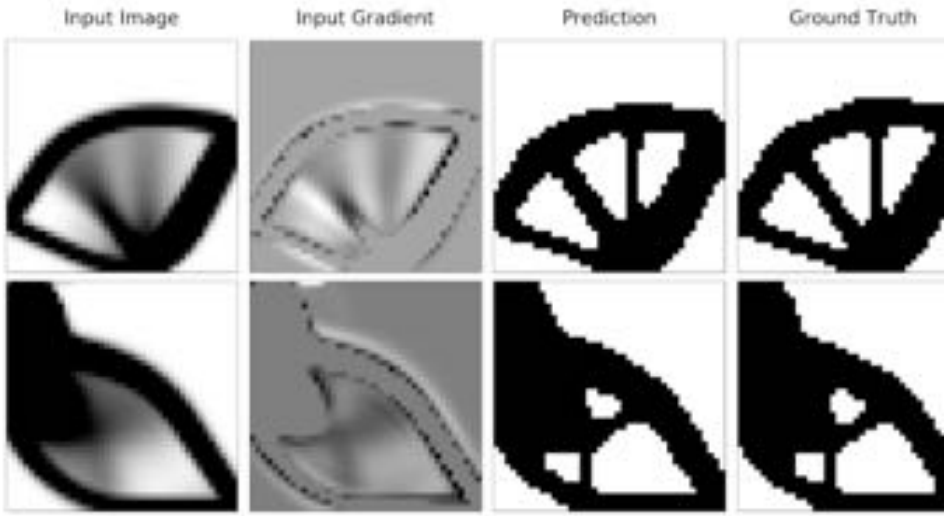
$$\begin{aligned}
&\underset{x}{\text{minimize}} && F = F(\mathbf{u}(\rho), \rho) = \int_{\Omega} f(\mathbf{u}(\rho), \rho) \mathrm{d}V \\
&\text{subject to} && G_0(\rho) = \int_{\Omega} \rho \mathrm{d}V - V_0 \leq 0 \\
& && G_j(\mathbf{u}(\rho), \rho) \leq 0 \text{ with } j = 1, \ldots, m
\end{aligned}$$

Learning to Generate Long-term Future via Hierarchical Prediction

https://arxiv.org/pdf/1704.05831.pdf

Neural networks for topology optimization

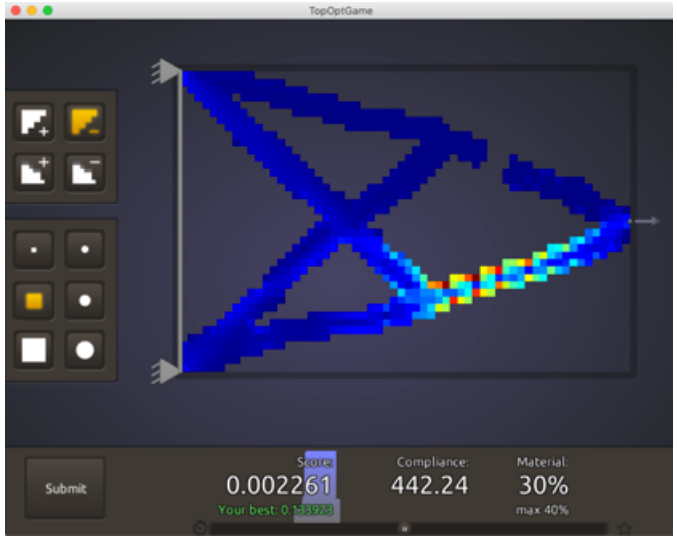




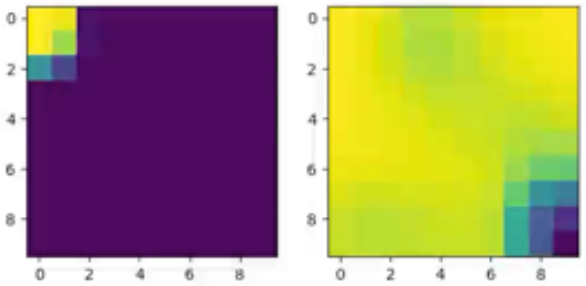
https://arxiv.org/abs/1709.09578

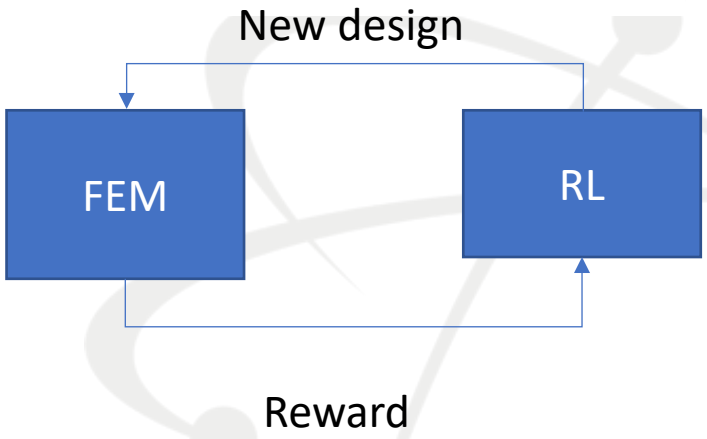
Reinforcement Learning to Topology Optimization

어디에 구멍을 뚫고 채울 것인가??

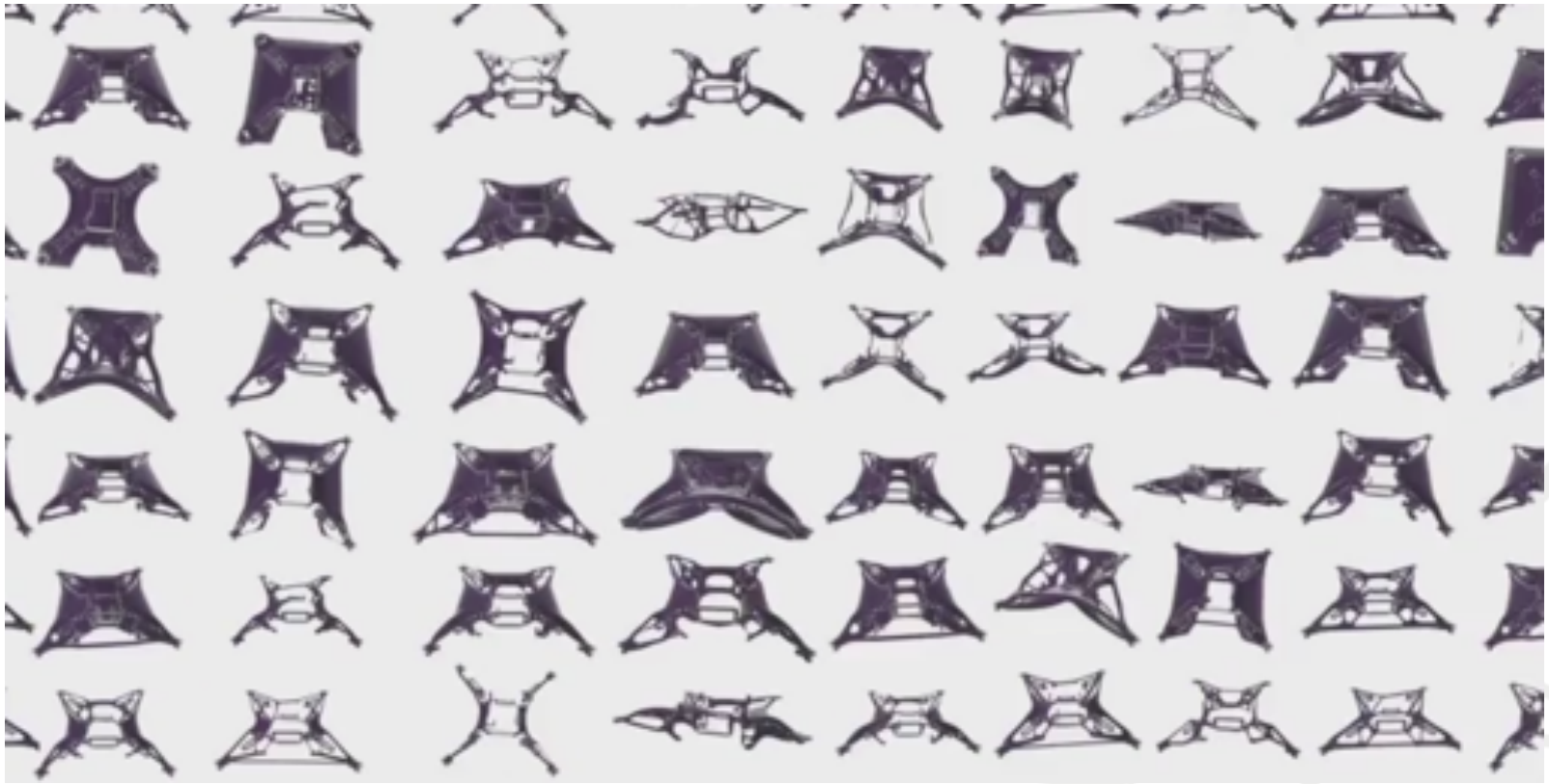


comp: 4797546068.03
vol: 0.0461726155559



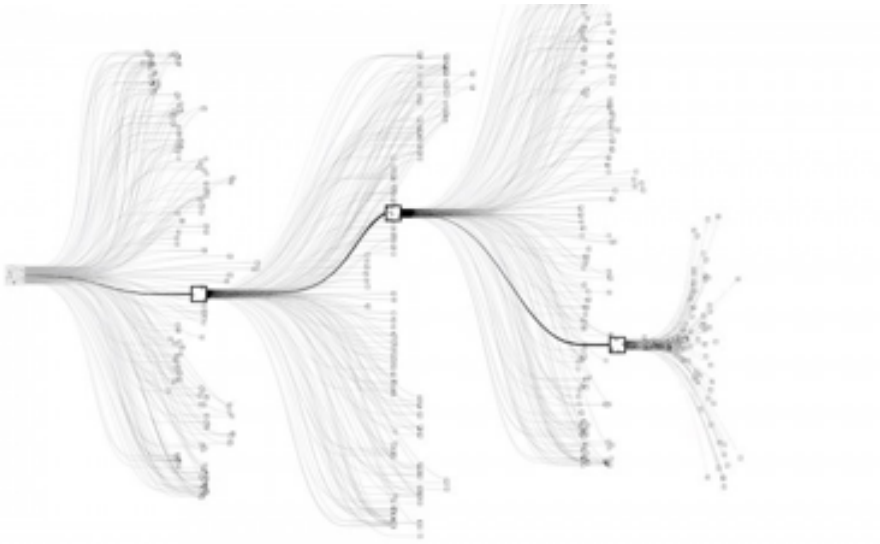


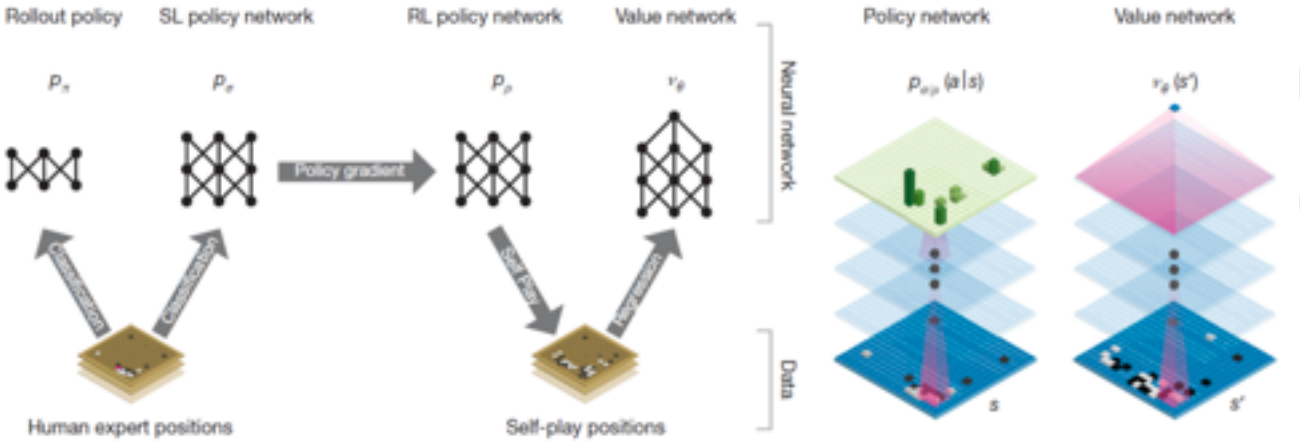
Accelerating topology optimization algorithm



과거 경험으로부터 알고리즘을 점점 개선시킬 수 있지 않을까?

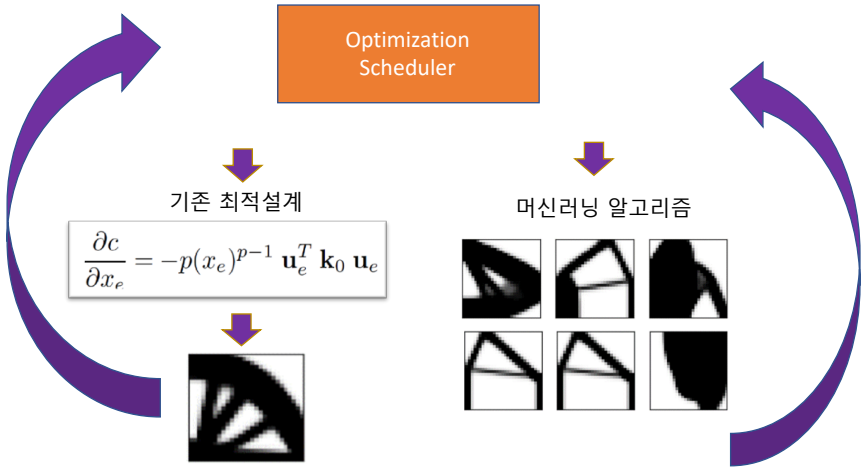
Ahpha Go? Fast simulator??





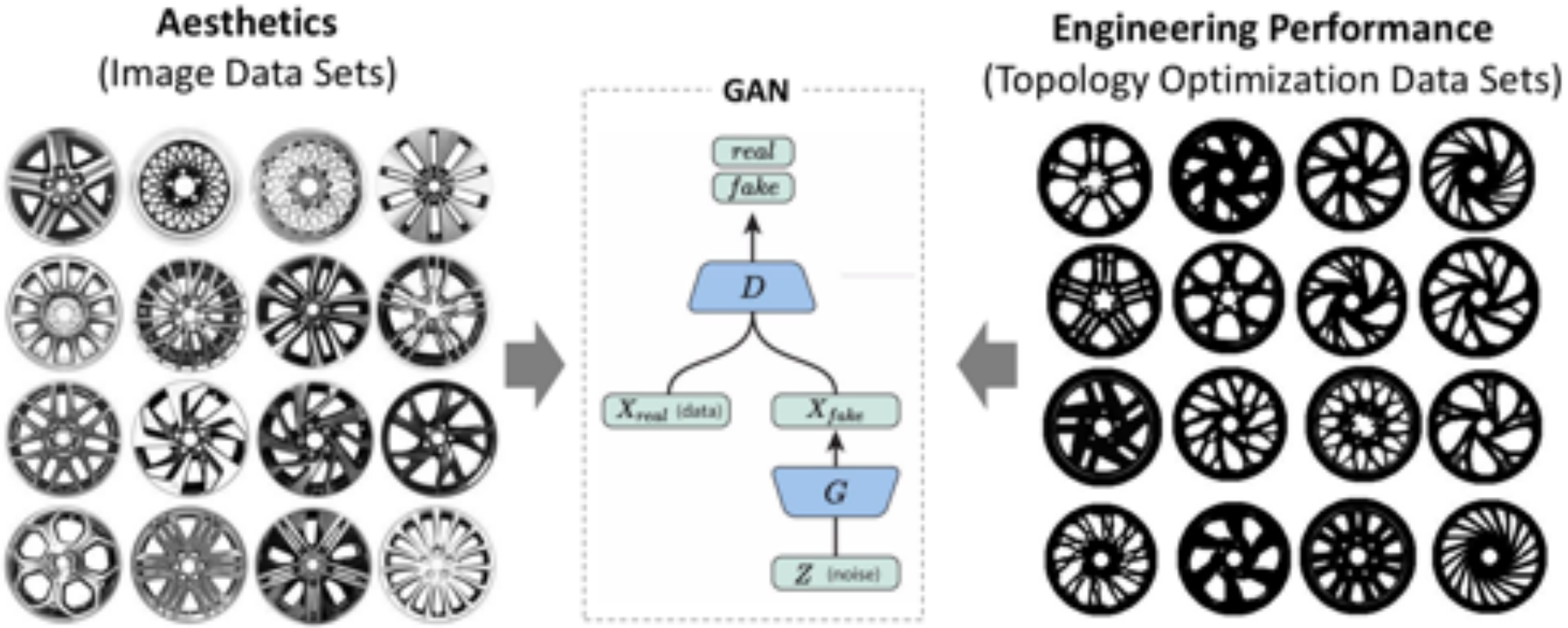
인공지능을 활용한 최적설계

최적설계의 가속화



목적함수의 다양화

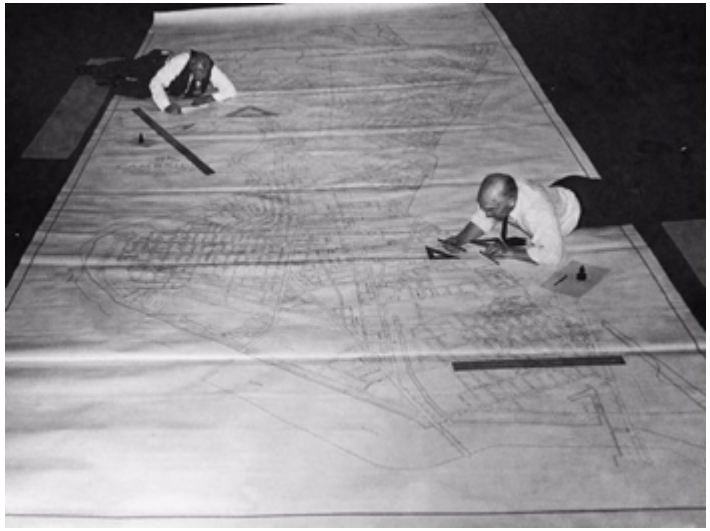
디자인을 고려한 최적설계

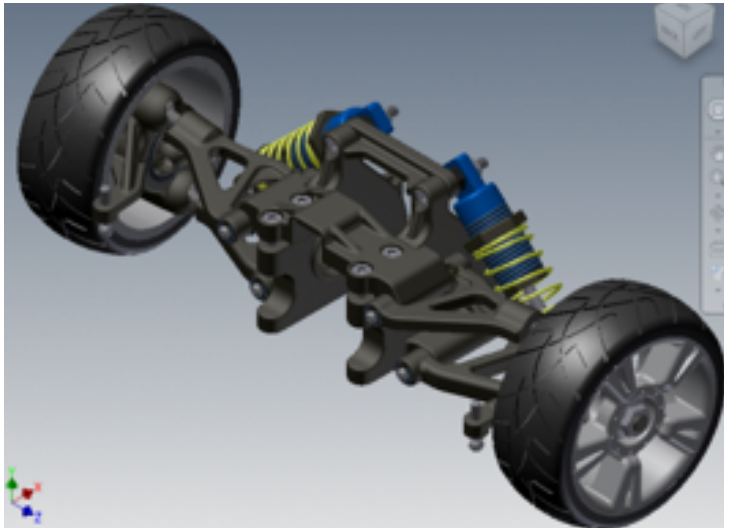


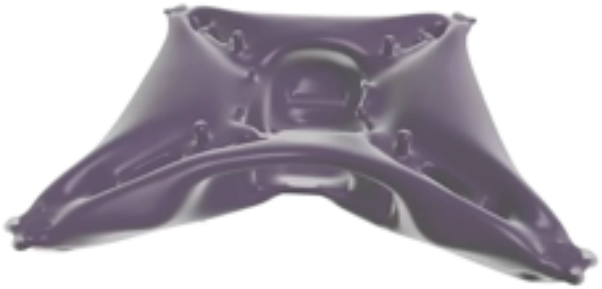
(숙명여대 기계공학과 강남우 교수)

-Oh, S., Jung, Y., Lee, I., & Kang, N. (2018, August). Design Automation by Integrating Generative Adversarial Networks and Topology Optimization. In *ASME 2018 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference* (pp. V02AT03A008-V02AT03A008). American Society of Mechanical Engineers-

AI는 도구다.







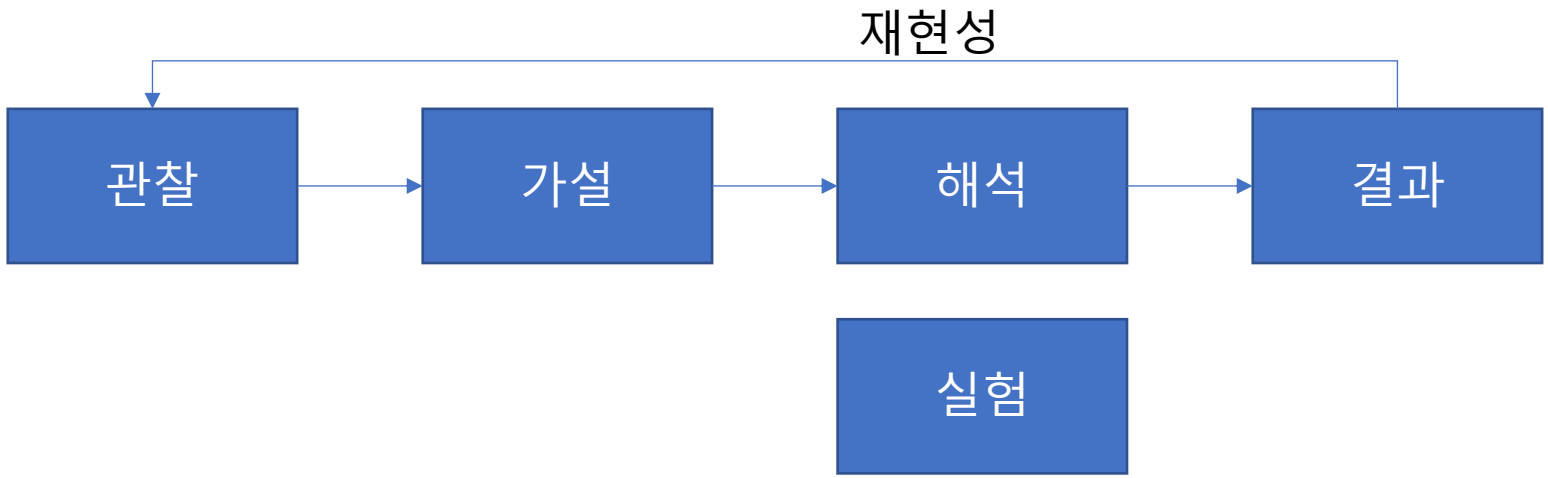
문제해결을 위한 방법론들...

Math

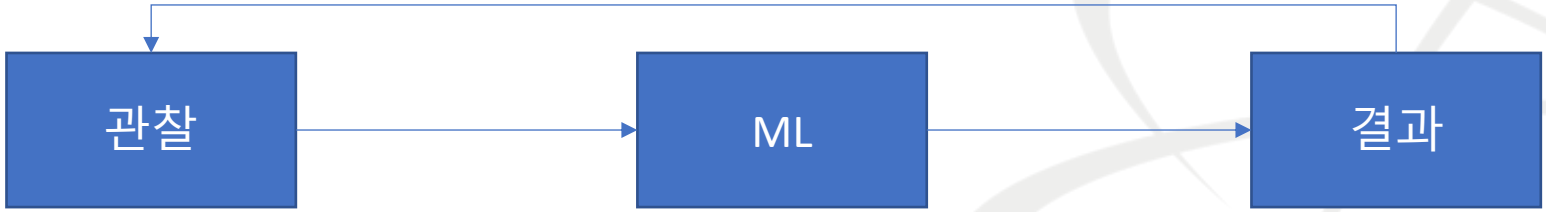
Rule based

ML

ML은 귀납적 문제해결 방법이 아닐까요?



고전적인 학문 (연역적 문제해결 기법?)



Machine learning (귀납적 문제해결 기법?)

ML은 지금의 컴퓨터와 같이 존재라고 생각합니다.

Hidden Figures (2017)

다 같이 힘을 합쳐 지구를 구해봅시다.

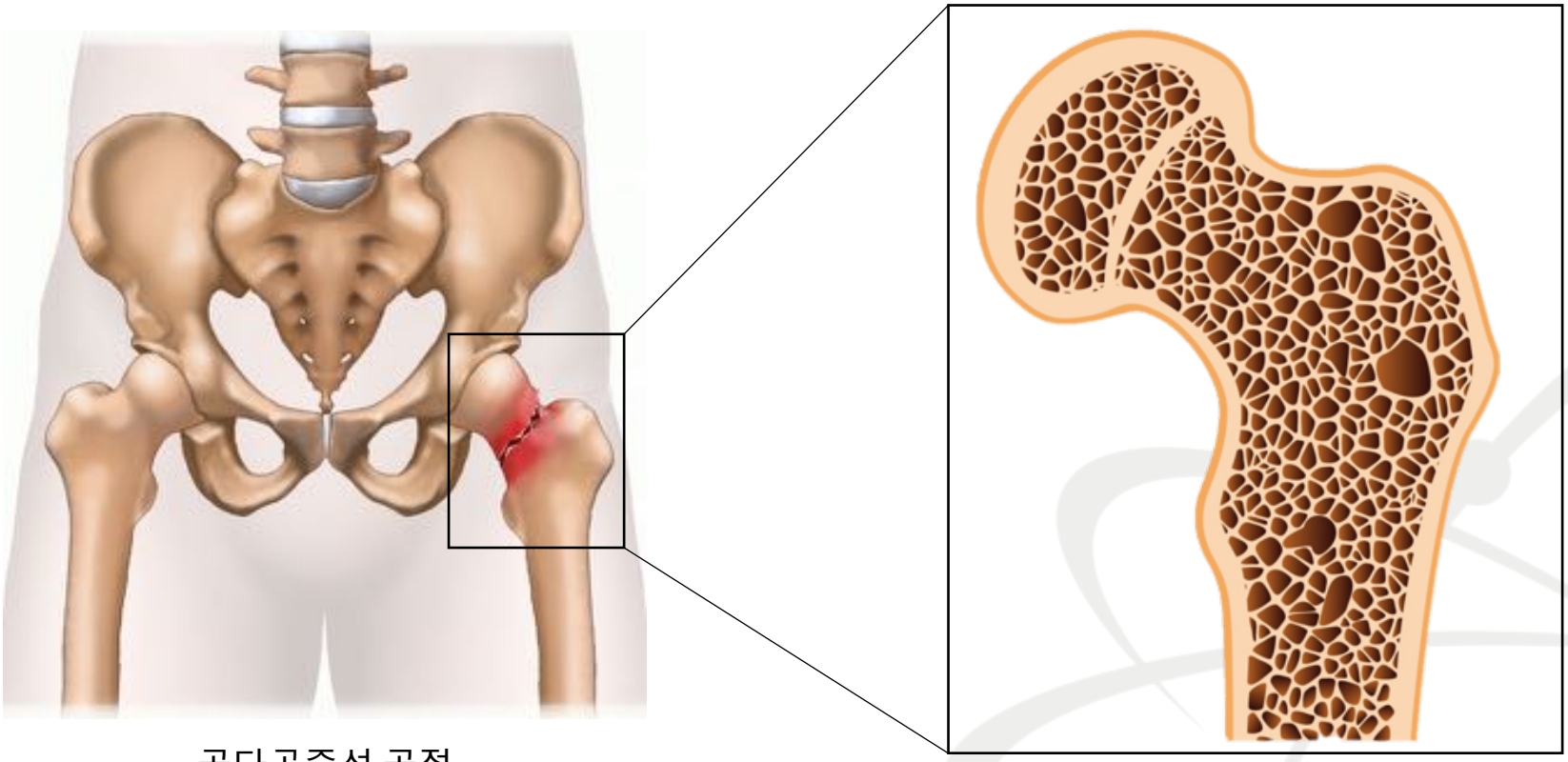
기존 방법론과 융합할 수 있는 방법은 없을까?

정해진 Domain 만 잘 풀어도 되는 문제가 없을까?

임의의 Domain 문제로 확장할 수 있지 않을까?

골다공증이란?

- 골량 감소 및 골질 악화로 인해 **골 강도가 감소**하여 **골절 위험성이 증가**하는 골격계 질환

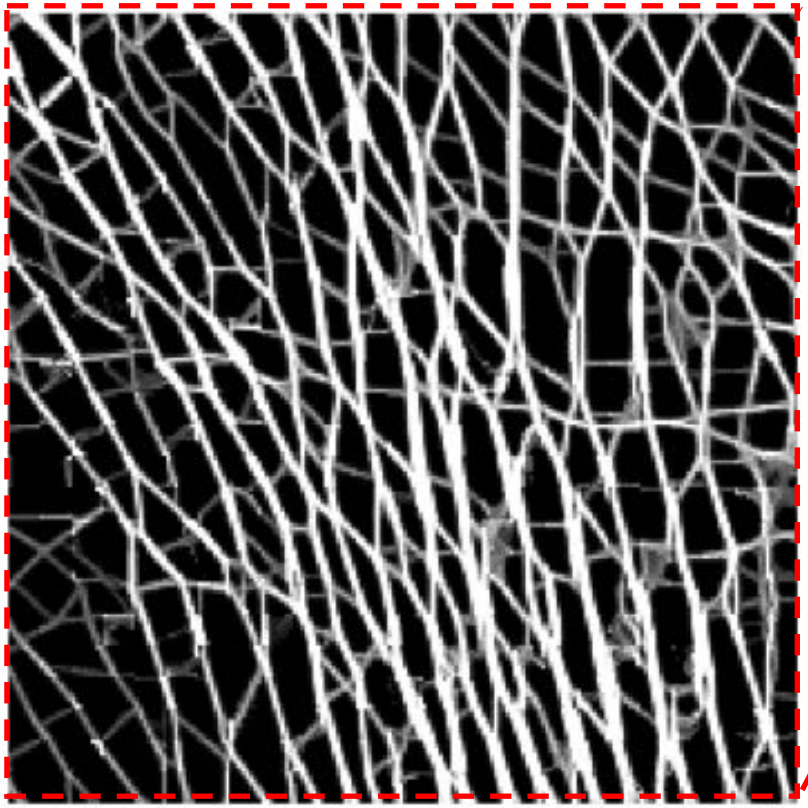


골다공증성 골절

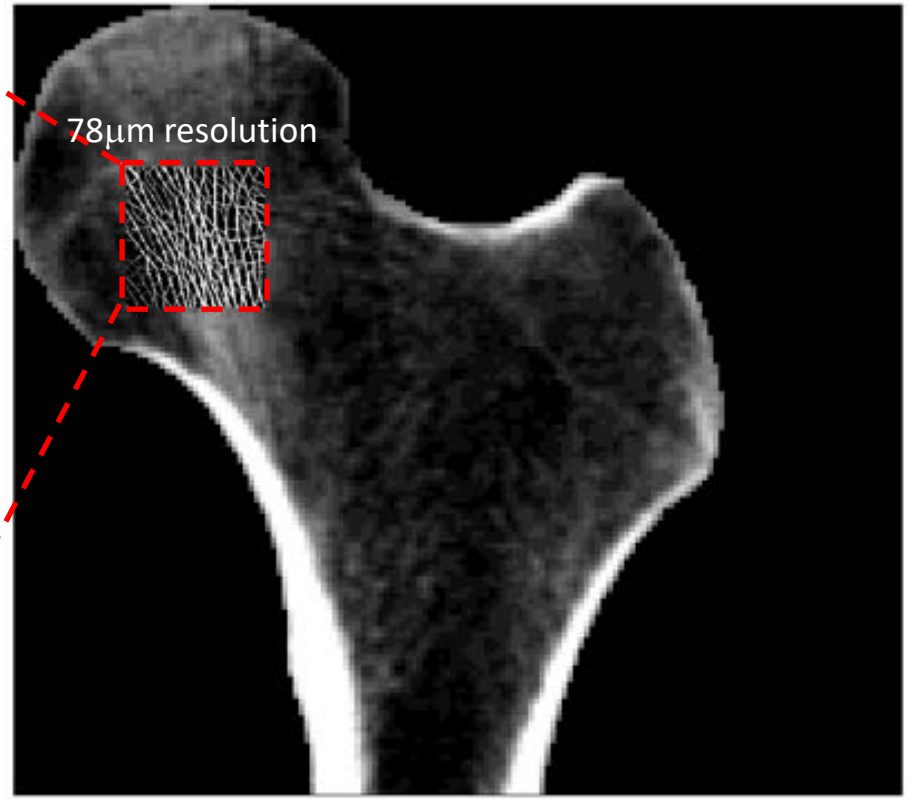
*KAIST 장인권, 계명대 김정진 교수 협업

골다공증 진단을 위한 뼈 CT 사진 고해상화

정확한 골다공증 진단을 위한 저선량 CT 사진 고해상화

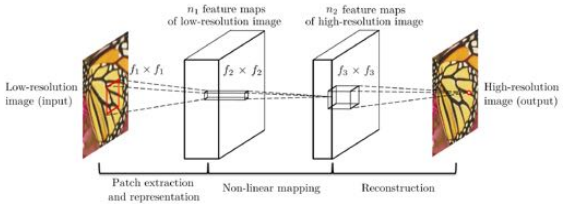
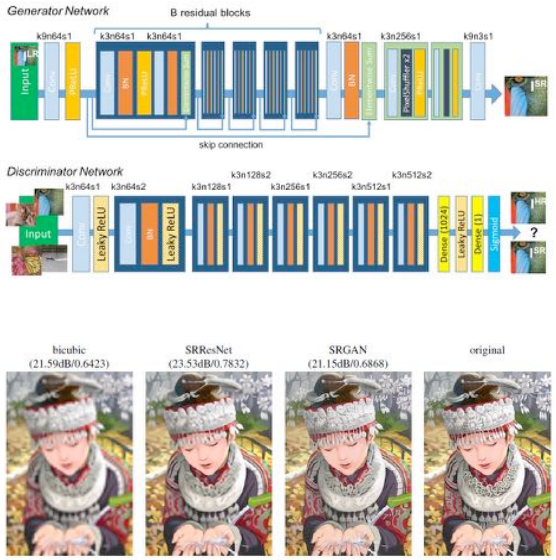
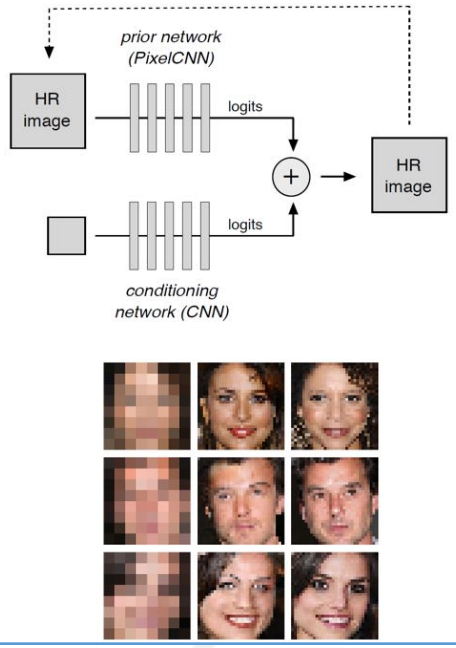


78μm resolution



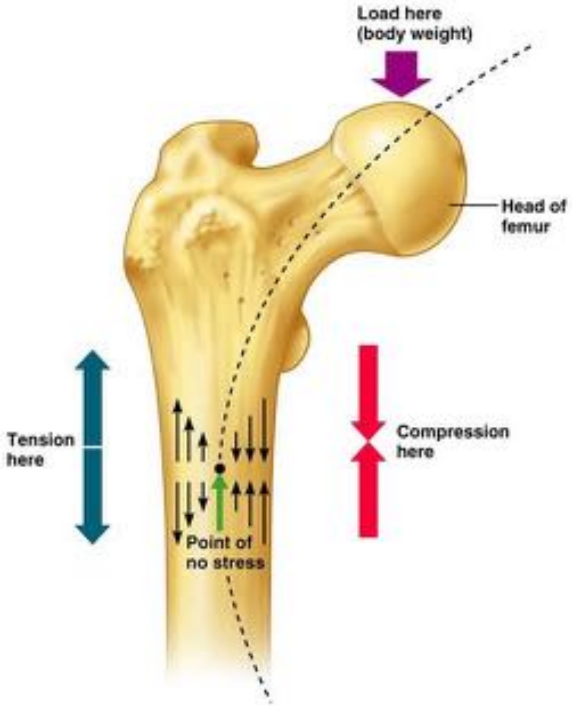
625μm resolution

인공신경망 기반 영상 고해상화 기술

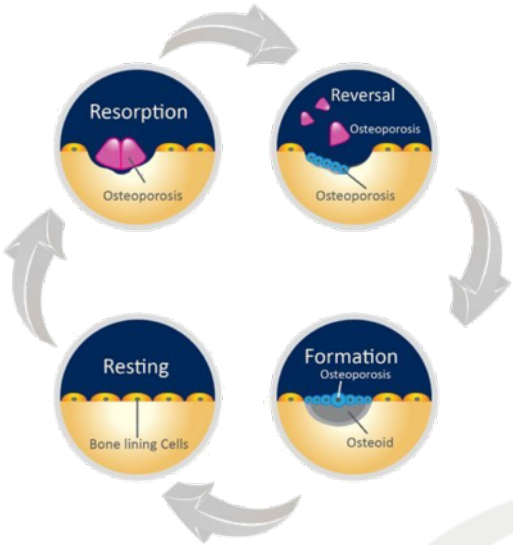
SRCNN [Dong, 2016]	SR-GAN [Ledig, 2017]	Pixel Recursive SR [Ryan, 2017]
		
• CNN 구조를 이용한 최초의 고해상화 논문	• Resnet 구조 및 GAN 을 고해상화에 적용한 최초의 논문 • Discriminator loss를 이용하여 보다 사실적인 복원이 가능.	• 고해상화 결과를 다시 입력으로 사용하여 Recursive 하게 고해상화.

골 재형성

- 골 재형성 과정은 **최소의 골량**으로 주어진 기계적 자극에 대해 **최대의 기계적 효율**을 얻는 골 미세구조를 생성함 (Wolff's law, 1892)



기계적 자극



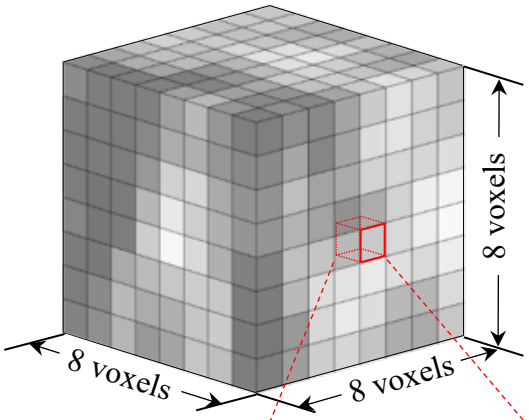
골재형성 과정

골 미세구조

위상최적설계 기반의 골 미세구조 복원

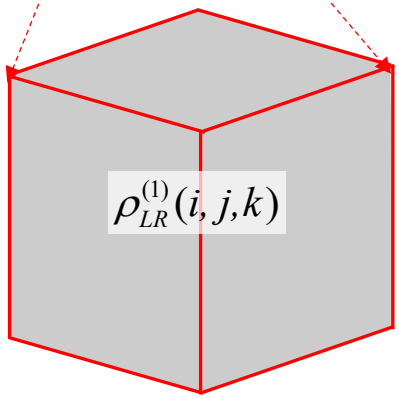
- 위상최적설계는 **외부 하중을 가장 효과적으로 지지할 수 있는 구조를 탐색**하는 최적설계 방법이며, 골 재형성(p.28)에서의 기본 원리인 Wolff's law와 개념적으로 유사*
- 위상최적설계를 통해 **저해상도 의료 영상의 골밀도 분포를 골 미세구조로 재구성** 가능**

* Jang, I.G., Kim, I. Y., & Kwak, B. B. (2009)
** Kim, J.J., Nam, J. & Jang, I.G. (2018)

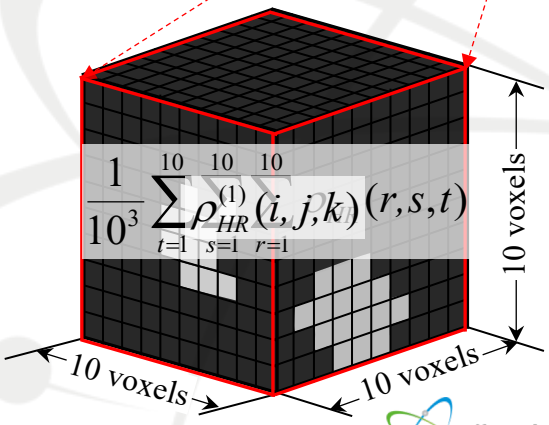


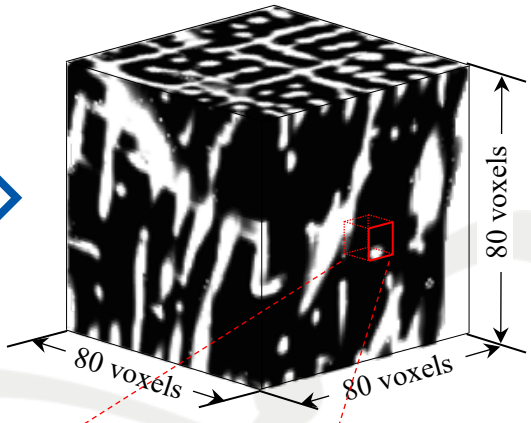
$$\text{Minimize} \quad f(\boldsymbol{\rho}) = \sum_{l=1}^{L} c_l \left(\frac{1}{2}\mathbf{u}_l^T \mathbf{K} \mathbf{u}_l\right)$$

$$\text{Subject to} \quad g_m(\boldsymbol{\rho}) = \frac{1}{N_m}\left\| \boldsymbol{\rho}_{HR}^{(m)} - \boldsymbol{\rho}_{LR}^{(m)} \right\|^2 \le \varepsilon_1 \quad (m = 1, 2, \cdots M)$$



$\cong$

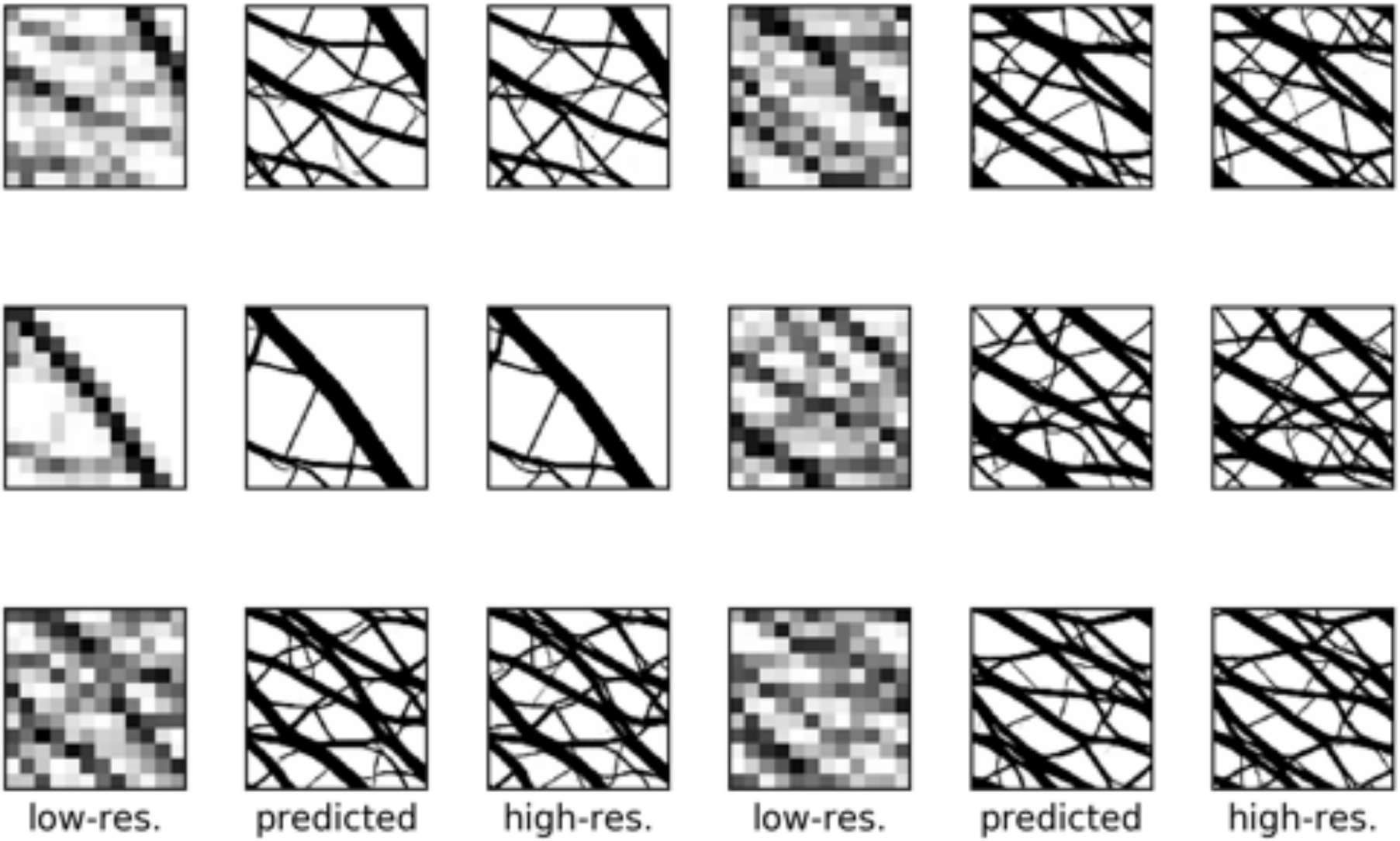




인공지능 기반의 임상 골격계 영상 재구성 알고리즘 개발

ACSMO 2018, Best Student Paper

고해상화 결과 예



기존 방법론과 융합할 수 있는 방법은 없을까?

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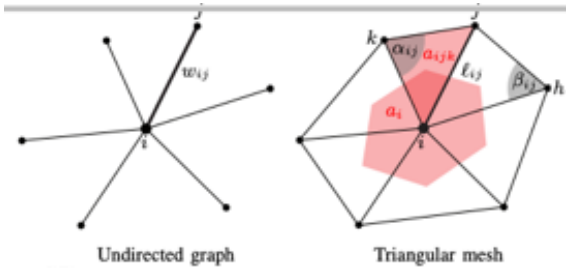
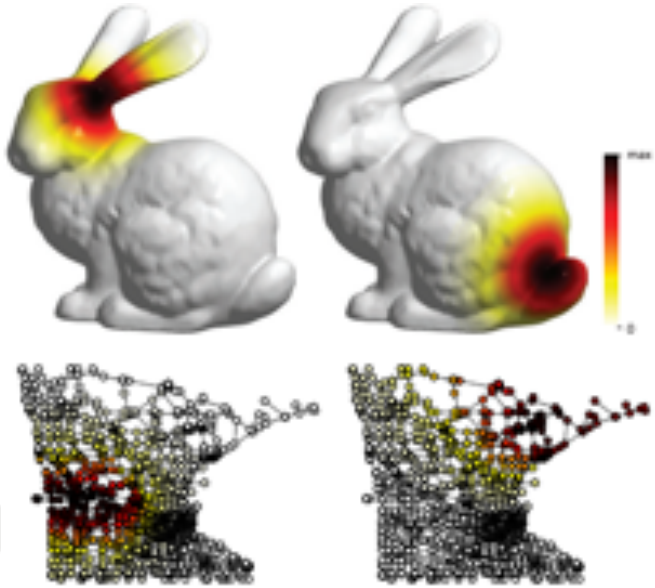
임의의 Domain 문제로 확장할 수 있지 않을까?

Geometric deep learning: going beyond Euclidean Data

Dichotomy of Geometric deep learning methods

Method	Domain	Data
Spectral CNN [52]	spectral	graph
GCNN/ChebNet [45]	spec. free	graph
GCN [77]	spec. free	graph
GNN [78]	spec. free	graph
Geodesic CNN [47]	charting	mesh
Anisotropic CNN [48]	charting	mesh/point cloud
MoNet [54]	charting	graph/mesh/point cloud
LSCNN [89]	combined	mesh/point cloud





https://doi.org/10.1016/j.buildenv.2018.05.026

MeshNet: Mesh Neural Network for 3D Shape Representation

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{feng-yt15, zxb, gaoyue}@tsinghua.edu.cn, {evanfeng97, haoxuanyou}@gmail.com

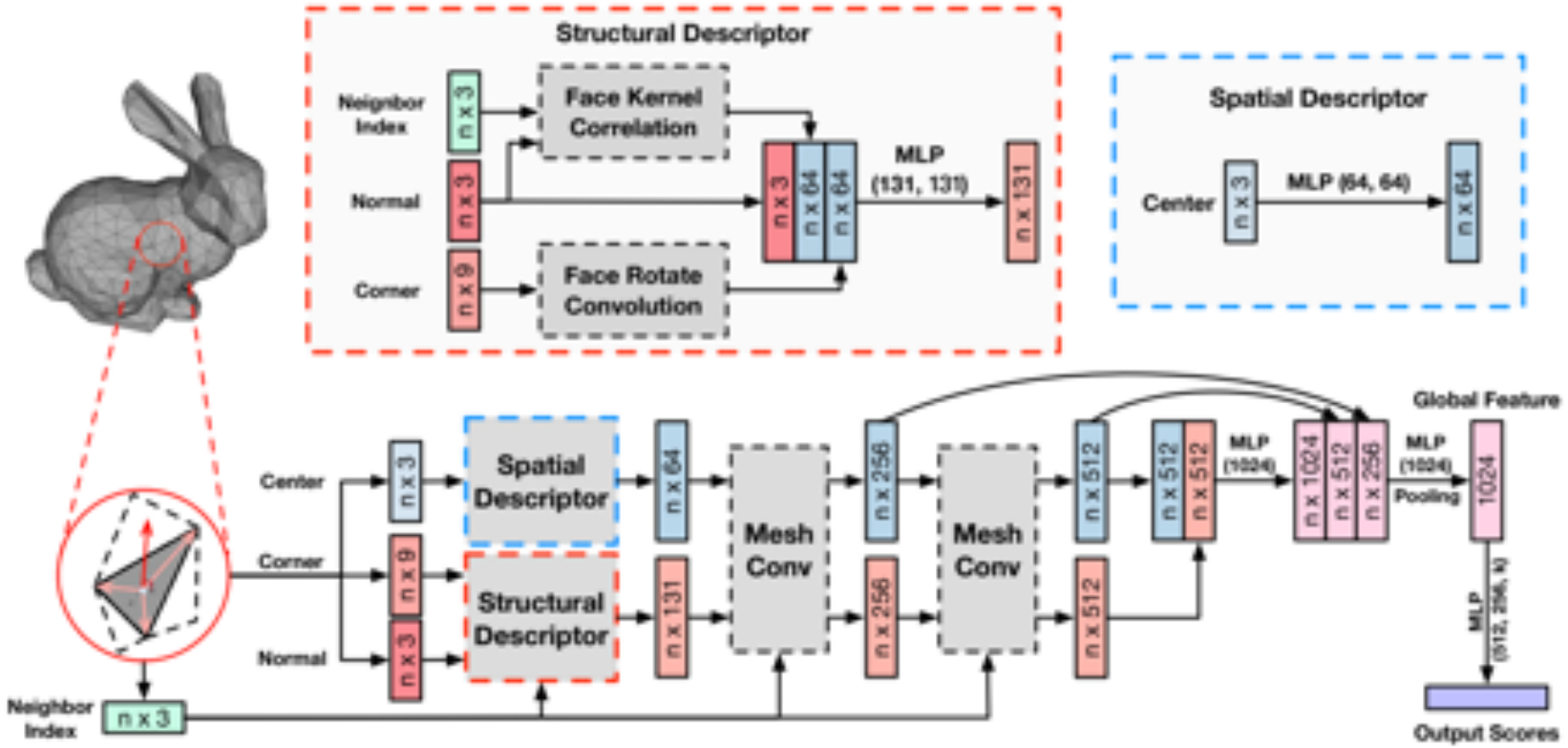
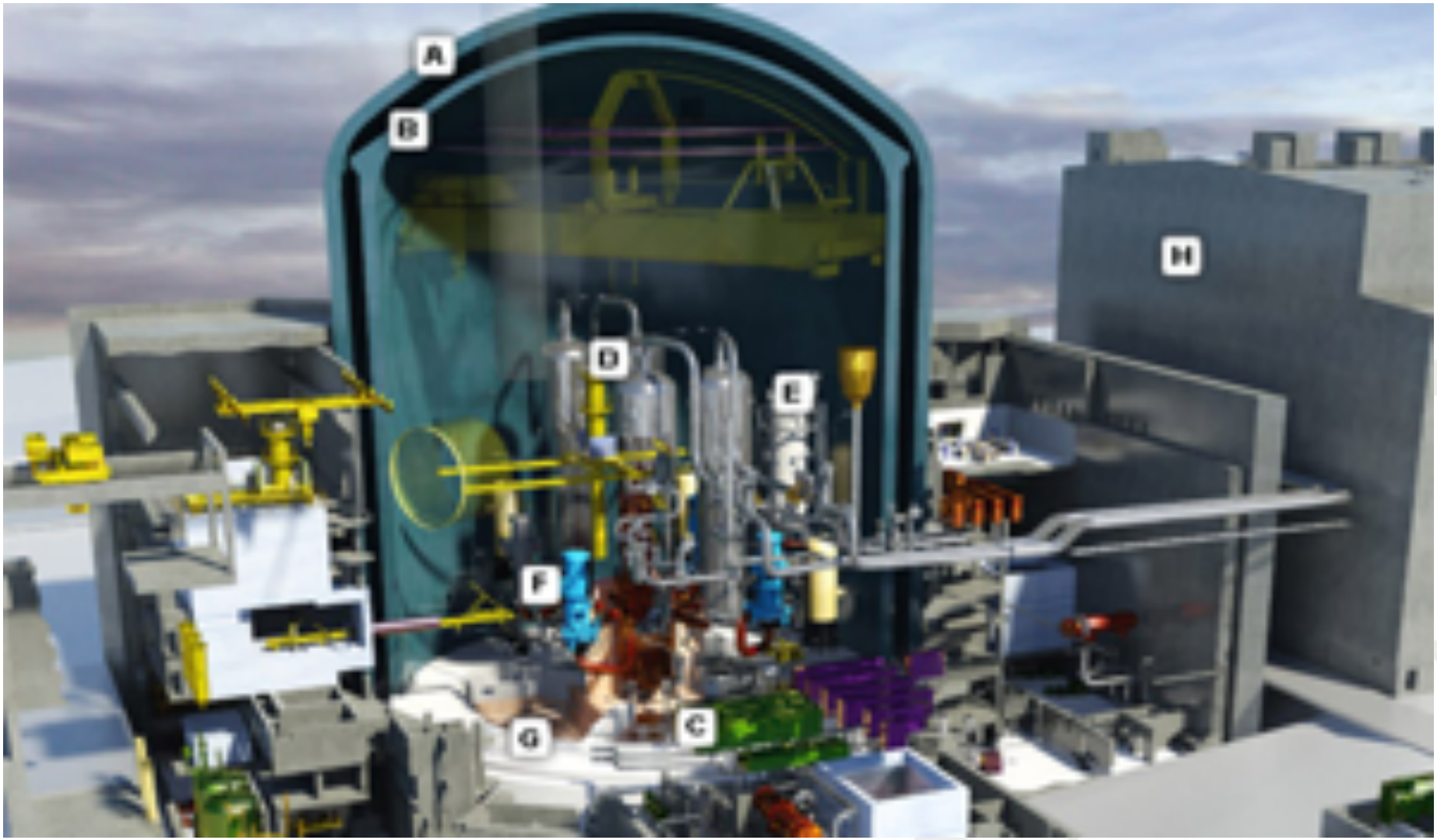


Figure 2: **The architecture of MeshNet.** The input is a list of faces with initial values, which are fed into the spatial and structural descriptors to generate initial spatial and structural features. The features are then aggregated with neighboring information in the mesh convolution blocks labeled as "Mesh Conv", and fed into a pooling function to output the global feature used for further tasks. Multi-layer-perceptron is labeled as "mlp" with the numbers in the parentheses indicating the dimension of the hidden layers and output layer.

원자력연구원의 인공지능 연구



원자력연구원의 인공지능 연구

- **원자로 설계 기술**
  - 원자로 노심 설계
  - 내부구조물 최적설계
- **원자로 물리현상 분석**
  - 핵연료 및 핵분열
  - 유동 및 열교환 해석
  - 내진해석
  - 유체 고체 연성해석
- **Digital Twin**
  - Model based RL
  - Data driven modeling
- **원자로 진단 기술**
  - 고장 감시 및 예지 진단
  - Anomaly detection
- **원자로 사고대응**
- **방사선 응용기술**
  - 플랜트 배관 건전성 감시
  - 영상의료
  - 통관 X-ray

NSSS Integrity Monitoring system

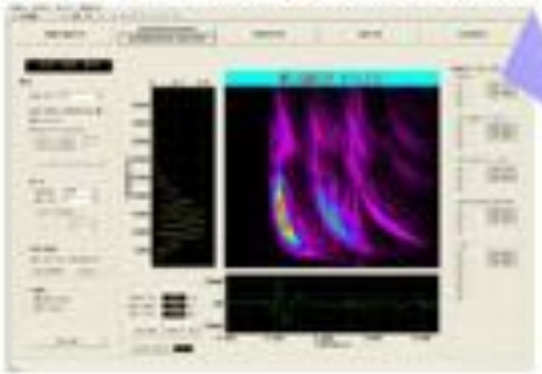
*전력경제신문

Loose part monitoring system (LPMS)

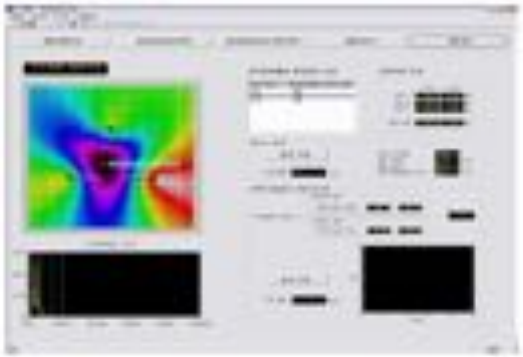
Mass Estimation [2]

1. Measured signal

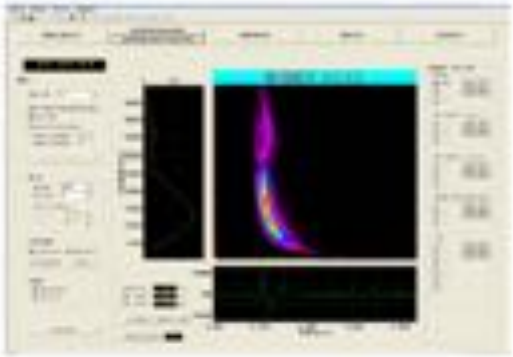
2. Eliminating reflected wave & noise



4. Mass estimation



3. Finding center frequency



LPMS

[2] D.-B. Yoon, J.H. Park et al, "Enhancement of Impact Mass Estimation Algorithm for a Plate Type Structure", Material Transactions, Vol. 48 no.06 (2007), pp. 1249-1253

*박진호, 원자로계통의 금속이물질 감시시스템, 2013 원전계측제어 심포지엄(NuPIC 2013)

후쿠시마 사고

The crisis at the Fukushima nuclear plant was "a profoundly man-made disaster", a Japanese parliamentary panel has said in a report.

The disaster "could and should have been foreseen and prevented" and its effects "**mitigated by a more effective human response**", it said.

BBC News (5 July 2012)

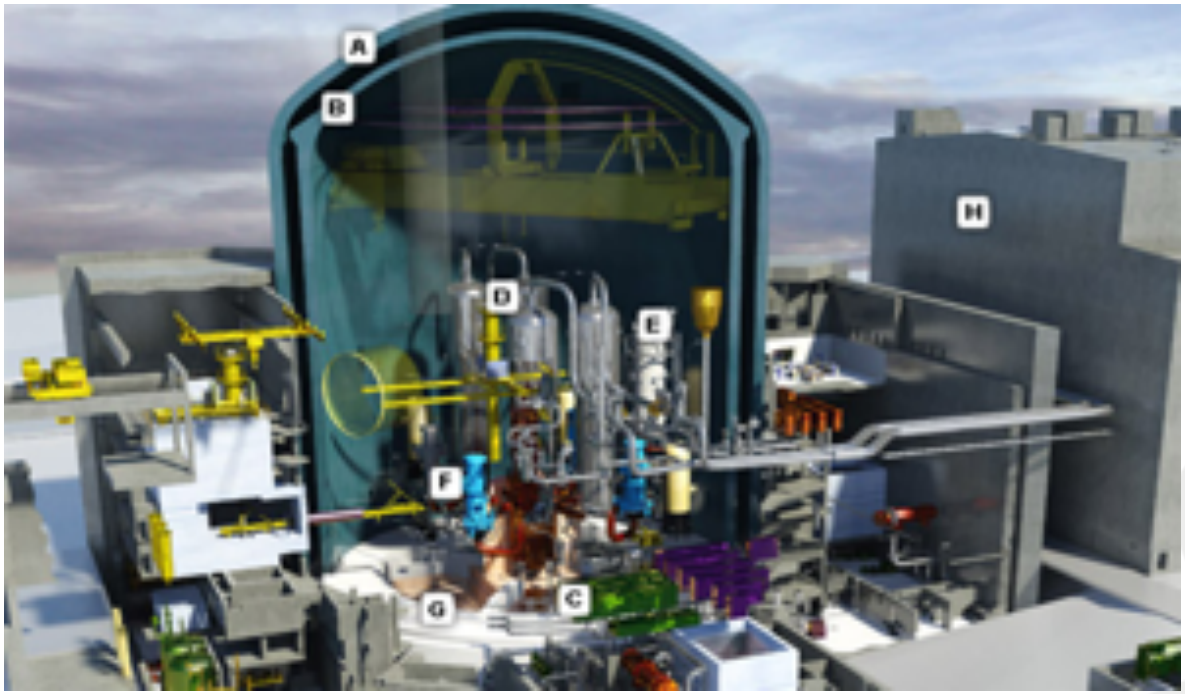
Fukushima fault: 'Man-made disaster' could have been prevented

The disaster at the Fukushima power plant may have been triggered by a tsunami, **but it was human error that made it into one of the worst-ever nuclear accidents in human history**, a Japanese Parliamentary panel says.

(RT news, 5 July 2012)

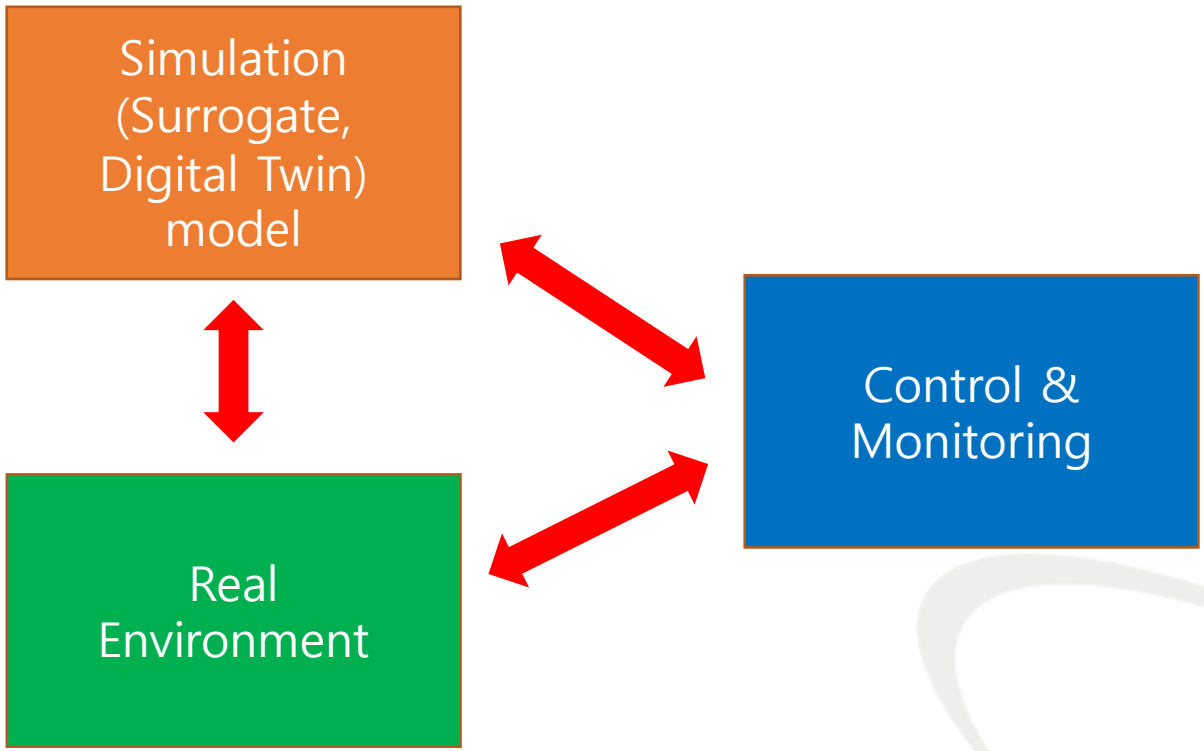
원자로의 Digital Twin을 이용한 사고 대응

- 후쿠시마 사고와 같은 상황에도 안전한 원자로



http://www.corys.com/en/steps/article/digital-twin-challenge-nuclear-power-plants

Digital Twin with machine learning



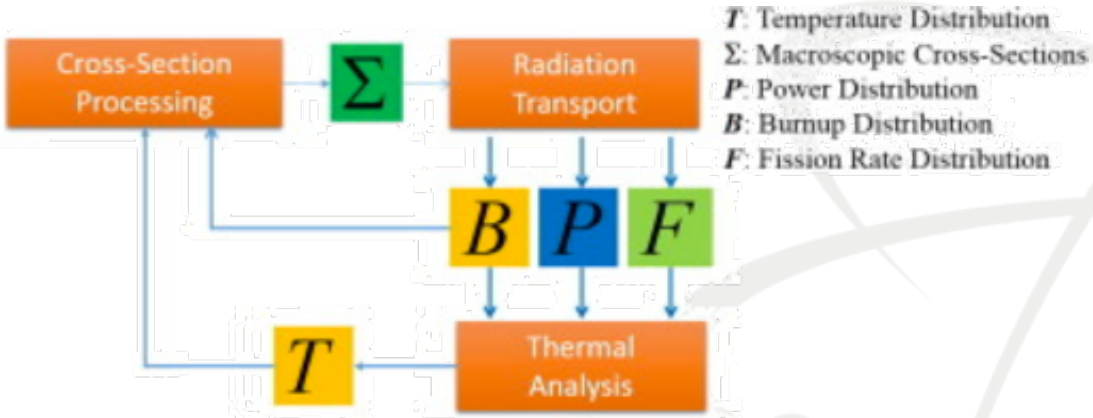
- 복잡한 다물리 현상을 빠르게 모사할 수 있는가?
- 어떤 데이터를 생성할 것인가?
- 실제 데이터와 차이는?

Dimensionality reducibility for multi-physics reduced order modeling

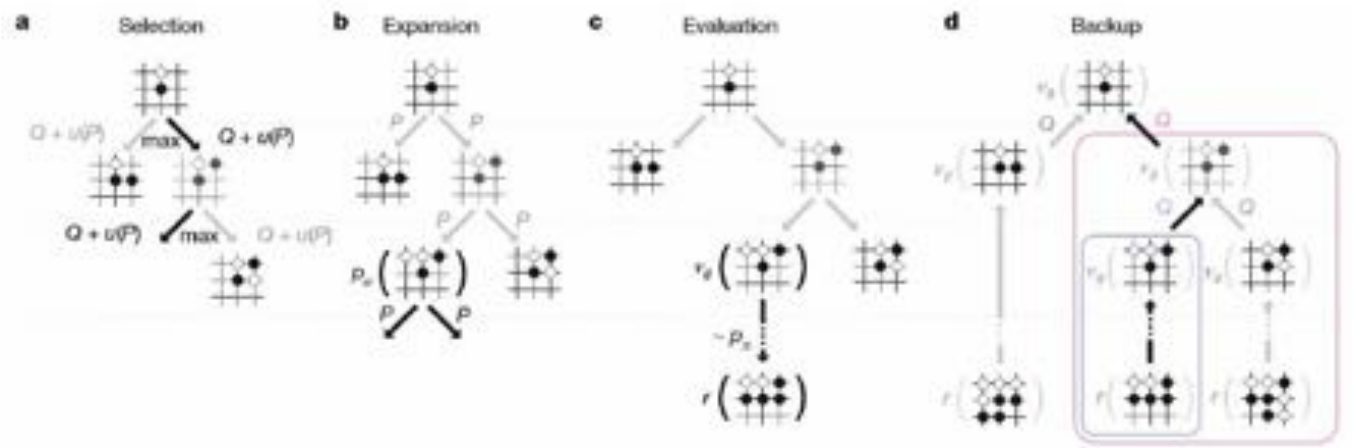
The final goal of this study is to construct a surrogate model for the coupled Rattlesnake-BISON models

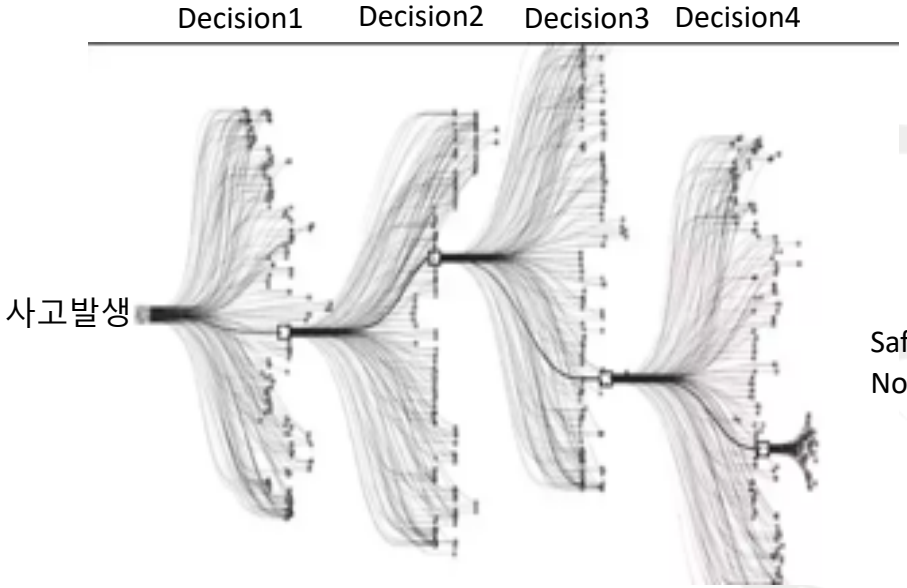
The computational cost needed for the construction of surrogate models for a multi-physics model can be significantly reduced if one employs dimensionality reduction to identify the effective DOF.

Another important conclusion of this study is that while fine mesh simulation is highly needed to accurately describe the multi-physics nature of system behavior, it comes at a great cost.



중대사고 대응 로직


a
Selection
b
Expansion
c
Evaluation
d
Backup
max
max


Decision1
Decision2
Decision3
Decision4
사고발생
Safe or
Not ?

'AI 메카 대덕' 만드는 연구자들…'오픈 커뮤니티' 포문

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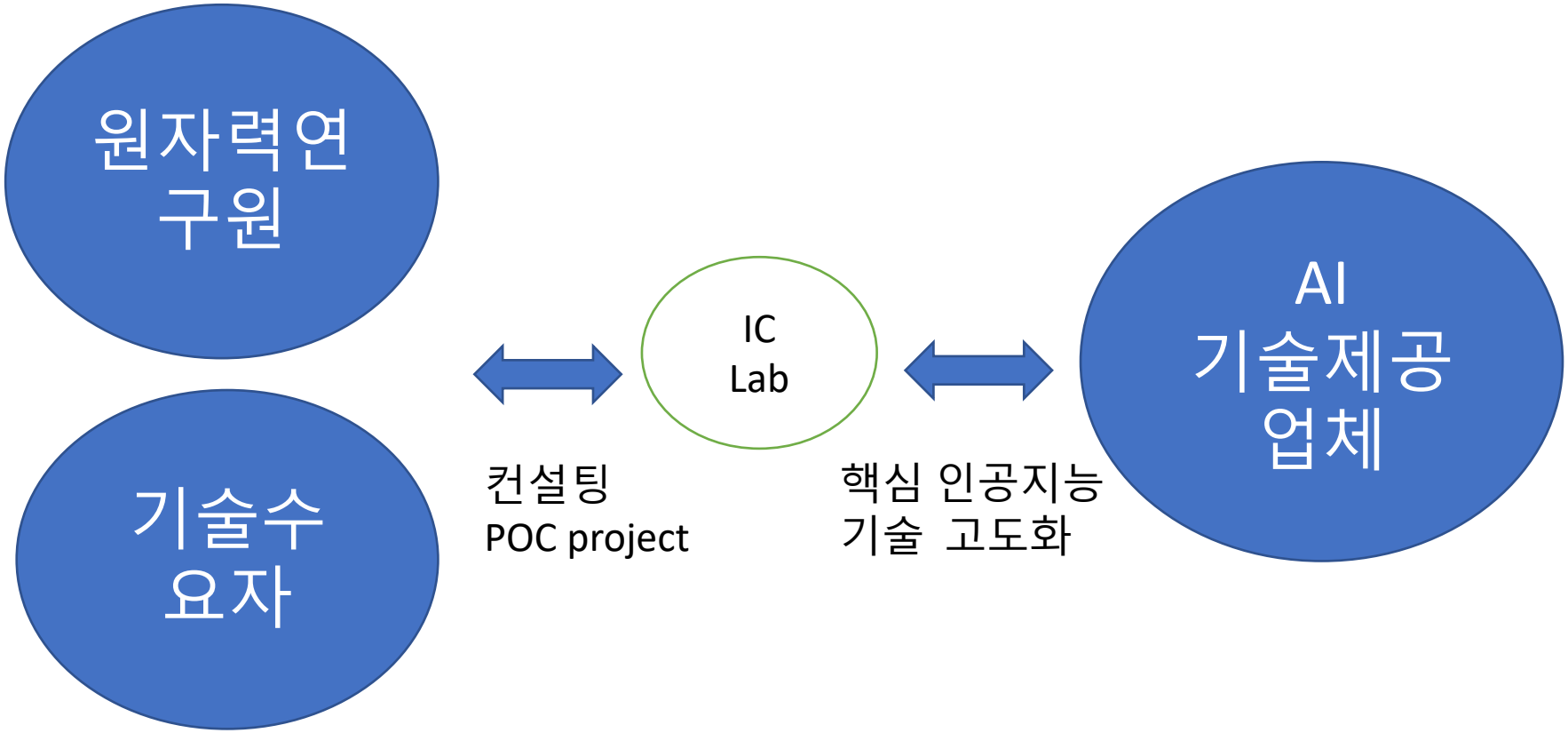
박성민 기자 sungmin8497@hellod

원자력연구원 지능형 컴퓨팅 랩



AI Doctor, AI 가정의학과, AI 상상팩토리