DOE & 인공신경망 기반 수냉식 냉각유로 최적화

서울과학기술대학교 / 정해찬

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INTRODUCTION

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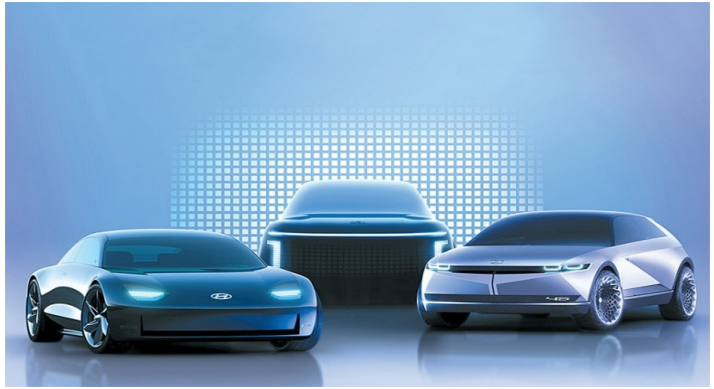
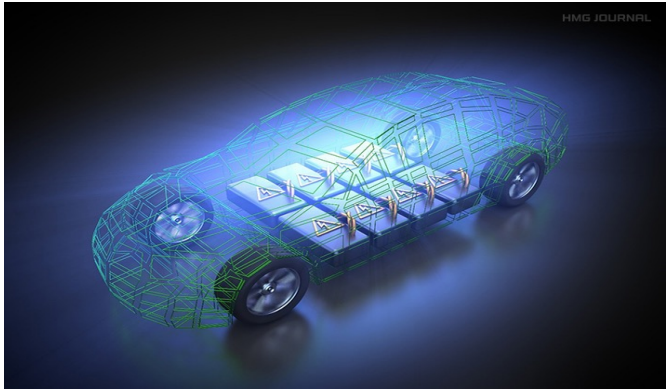
Intro

Background





"고성능화 & 소형화·경량화"

배터리 열관리 장치

Optimization

배터리시스템
성능 & 수명 ↑

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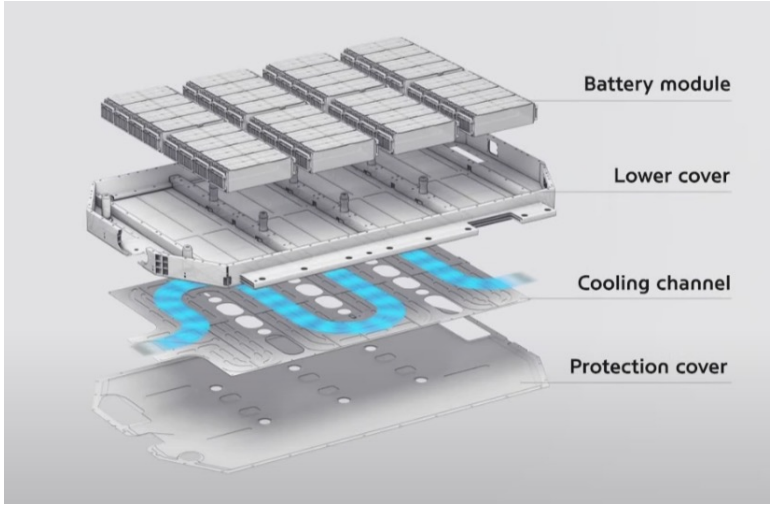
Intro

Background



냉각 유로
최적화 고려사항

배터리 온도

냉각 소비전력

온도

"Trade-Off"

압력

최적화 목표 :

"온도" & "압력 강하" 모두 고려한
유로 최적화

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Intro

Outline

최적화 목표 : **"온도" & "압력 강하"** 모두 고려한 유로 최적화

1. 모델링 & CFD 해석

creo®

Altair Simlab

2. 경향성 분석

Altair Knowledge Studio

3. ROM & DNN

Python

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MODELING & CFD

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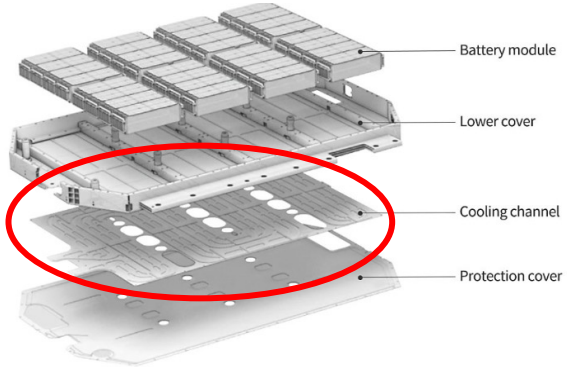
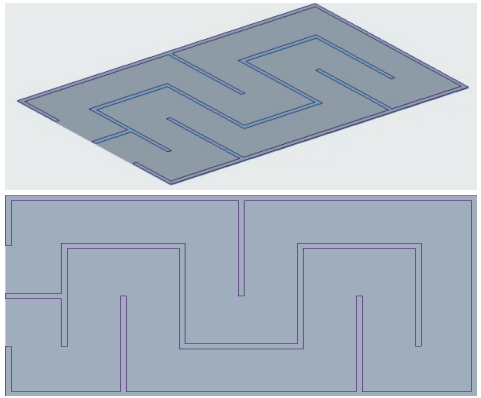
Modeling & CFD

Modeling



배터리 Cooling Plate의 유로(Channel)

Simplification



Creo 모델링

"Serpentine"

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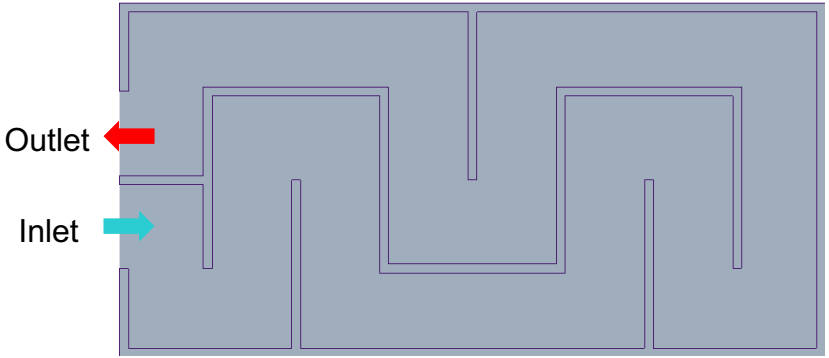
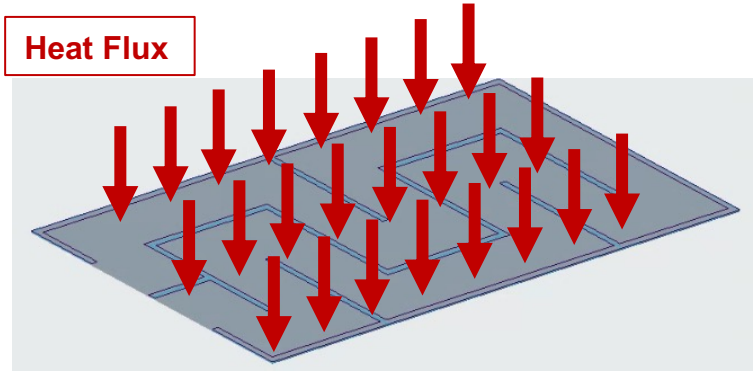
Modeling & CFD

Modeling





가정

- ✓ **배터리 발열은 윗면에서 고르게 일어남**
- ✓ **배터리는 일정한 heat generation**
- ✓ **주위로의 열손실 무시 (단열)**

물성치

Solid	Density	Specific Heat	Thermal Conductivity
Aluminum	$2700 kg/m^3$	908J/kg	237W/mK

Fluid	Density	Specific Heat	Viscosity	Thermal Conductivity
Water	$998 kg/m^3$	4182J/kg	$1 Pa \cdot s$	0.598W/mK

경계조건

- ✓ **Heat flux : 5000W/m^2**
- ✓ **Mass flow rate : 0.1kg/s**

- ✓ Jarrett, A., & Kim, I. Y. (2011). Design optimization of electric vehicle battery cooling plates for thermal performance
- ✓ Ye, B., Rubel, M. R. H., & Li, H. (2019). Design and optimization of cooling plate for battery module of an electric vehicle

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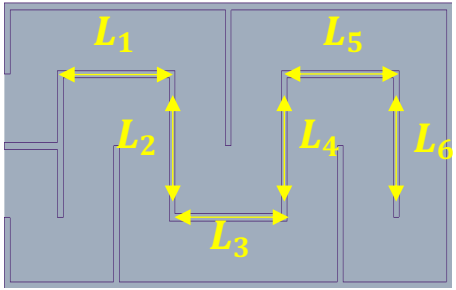
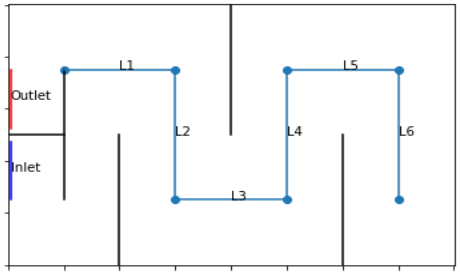
Modeling & CFD

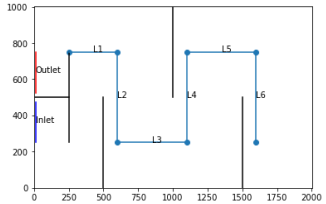
Design Parameter



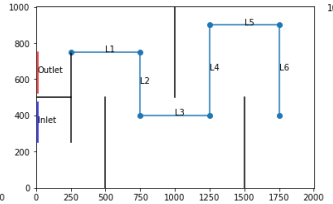


Reference

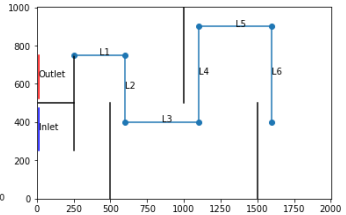
$L1 \sim L6$ 값 변화 (예시)



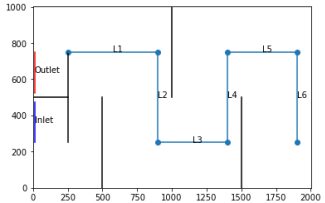
L1 Min.



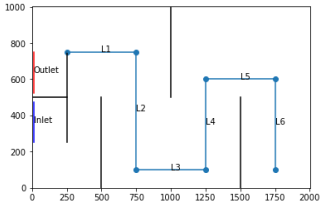
L2 Min.



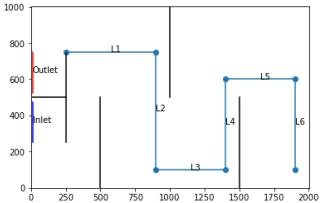
L1&L2 Min.



L1 Max.



L2 Max.



L1&L2 Max.

■ ■ ■

$L_1 \sim L_6$ 값 ⇨ **"Serpentine 형상" 결정**

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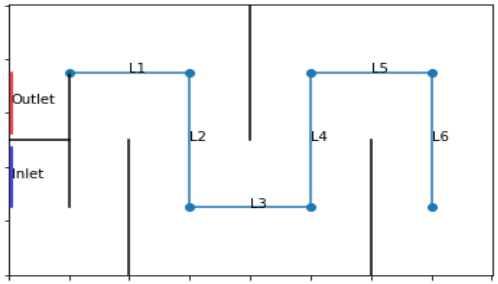
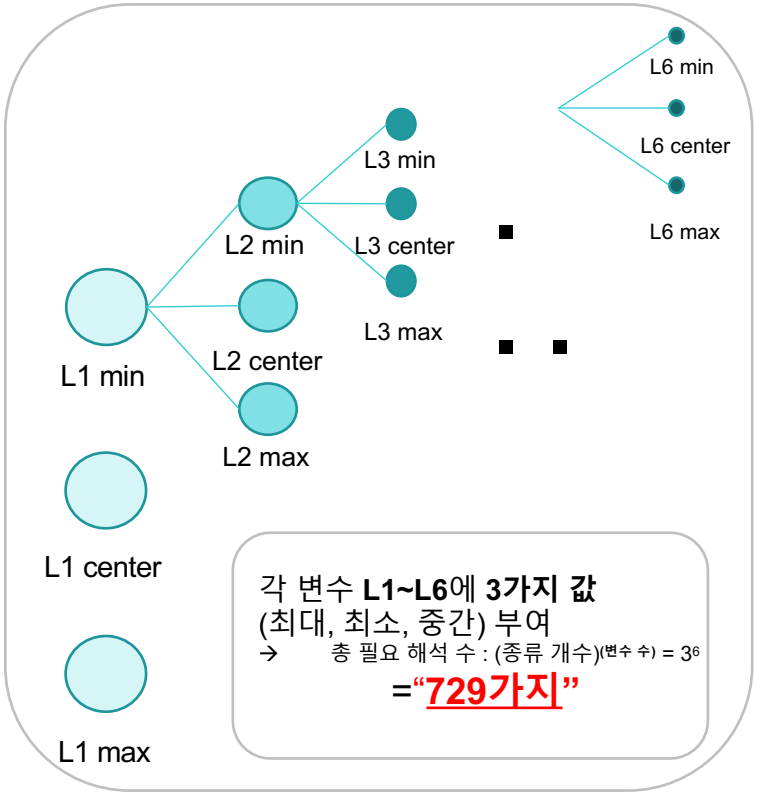
Modeling & CFD

Data Sampling



Reference



Altair SIMLAB
자동화 script & DOE

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Modeling & CFD

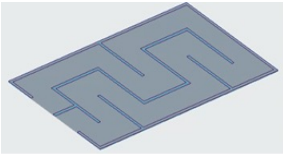
Data Sampling

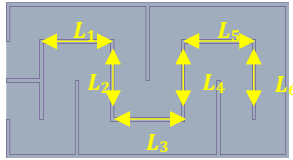
creo®

Parameter Setting

이름	유형	값	지정	액세스	소스	설명	제한
L1	실수	500.00000	☐	잠김	관계식		☐
L2	실수	500.00000	☐	전체	사용자 정의		☐
L3	실수	500.00000	☐	전체	사용자 정의		☐
L4	실수	500.00000	☐	전체	사용자 정의		☐
L5	실수	500.00000	☐	전체	사용자 정의		☐
L6	실수	500.00000	☐	전체	사용자 정의		☐

Geometry Modeling





Parameter Control

Geometry import

CFD anlaysis

Result save

Repeat
(729 times)

Result Analysis

“Optimized Design”

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DATA ANALYSIS

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Data Analysis

Objective function

"판단 기준"

$$\boldsymbol{Score = 100\times\left[\alpha\times\frac{T}{T_{ref}}+(1-\alpha)\times\frac{P}{P_{ref}}\right]}$$

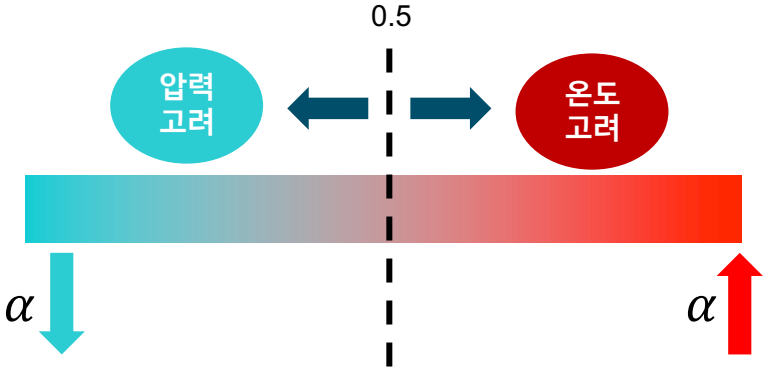
Ex) $T_{ref} = 30,\ P_{ref} = 3000$ 라고 가정.

If $T = 30, P = 3000$

→ $Score = \mathbf{100}\times\left[\boldsymbol{\alpha}\times\frac{\mathbf{30}}{\mathbf{30}}+(\mathbf{1}-\boldsymbol{\alpha})\times\frac{\mathbf{30}}{\mathbf{30}}\right] = 100\times[1] =$ **100점**

If $T = 20, P = 2000$

→ $Score = \mathbf{100}\times\left[\boldsymbol{\alpha}\times\frac{\mathbf{20}}{\mathbf{30}}+(\mathbf{1}-\boldsymbol{\alpha})\times\frac{\mathbf{2000}}{\mathbf{3000}}\right] = 100\times[\frac{2}{3}] =$ **66.67점**



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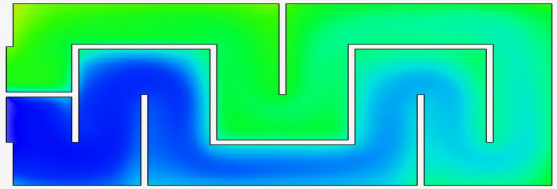
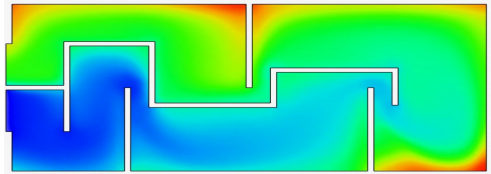
Data Analysis

Objective function

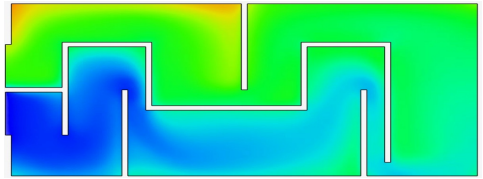


Reference	
T[℃]	P [Pa]
41.08	2567.38

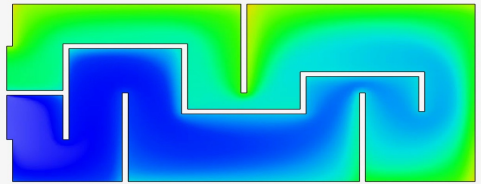
DOE
최적 설계안



$\alpha = 0.3$	
T [%]	P [%]
10.19	-7.00
Score : 95.90	



$\alpha = 0.5$	
T [%]	P [%]
6.30	-0.20
Score : 97.03	



$\alpha = 0.7$	
T [%]	P [%]
-2.17	12.00
Score : 99.52	

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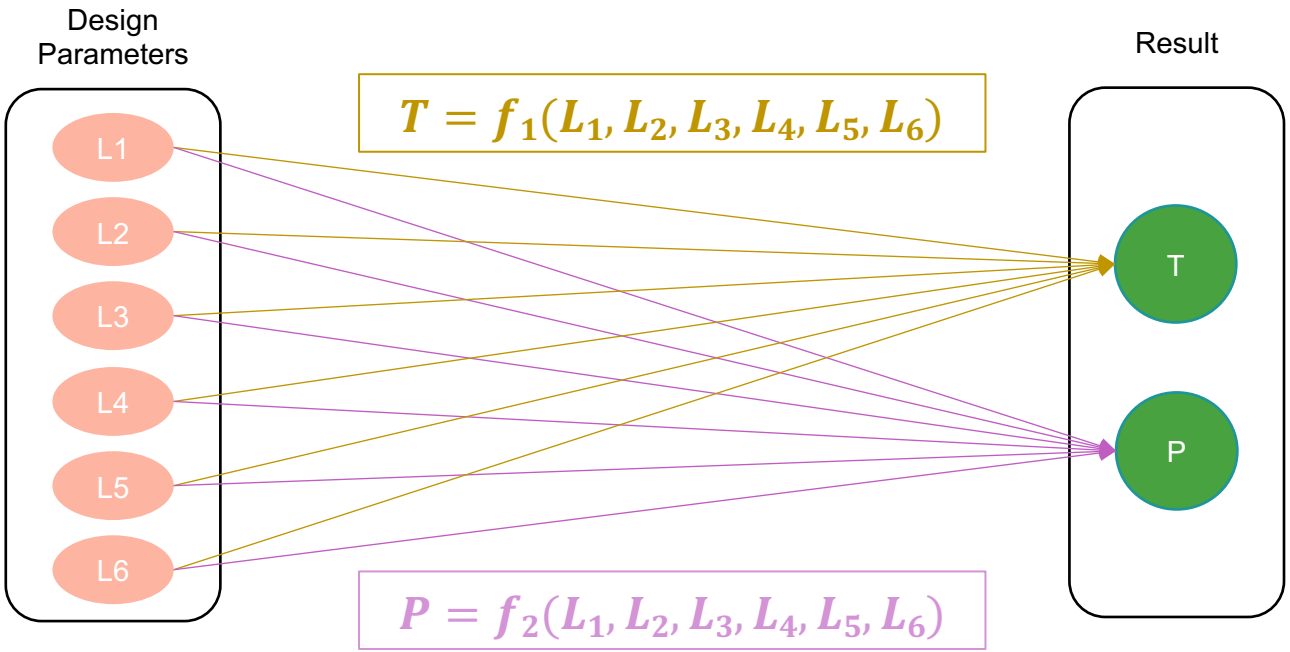
Data Analysis

Analysis

L1~L6 & T, P 관계 파악



→ f_1, f_2은 어떤 양상으로 표현될지?

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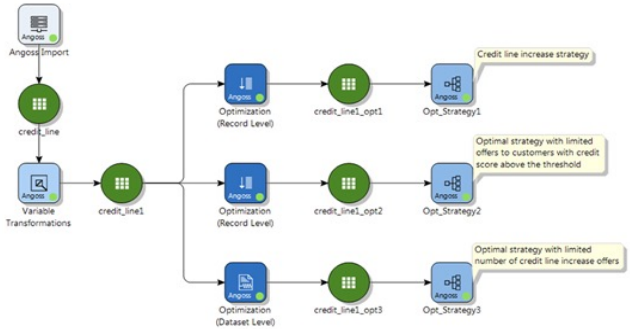
Data Analysis

Analysis

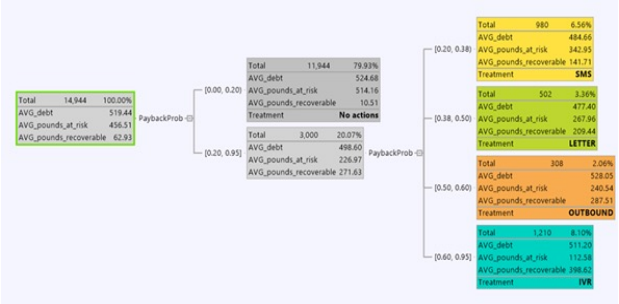
729개 데이터

Knowledge Studio

WorkFlow



Visualization



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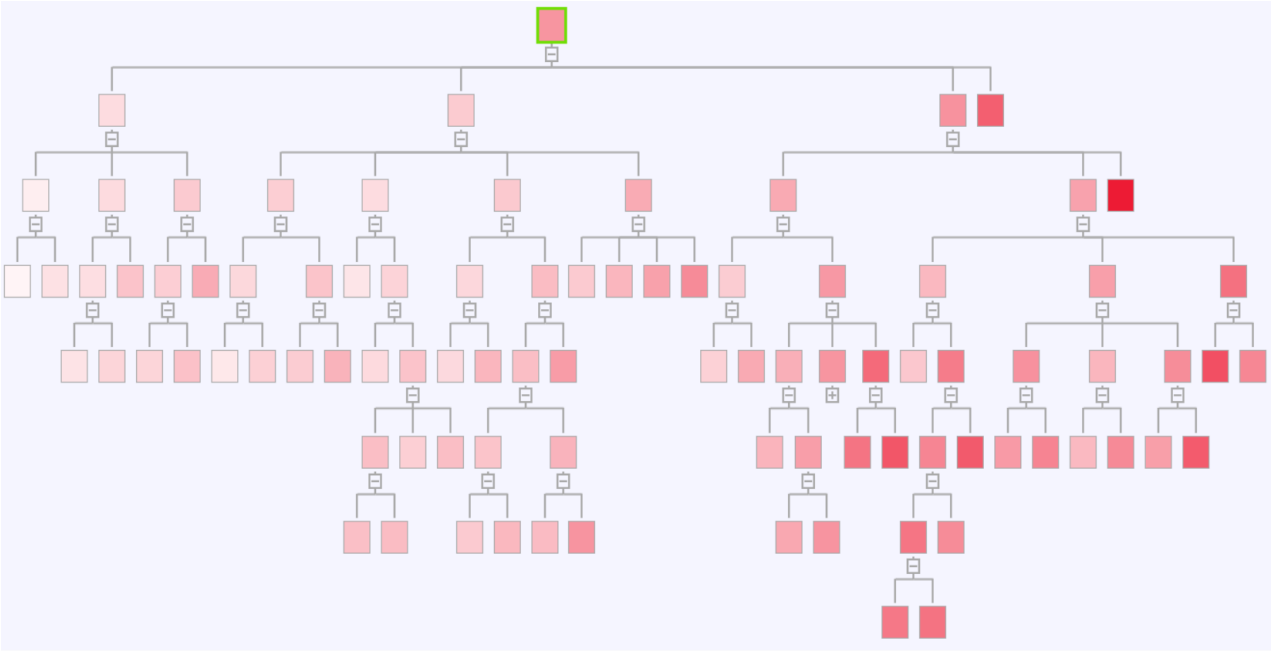
Data Analysis

Analysis

Good Case

Bad Case



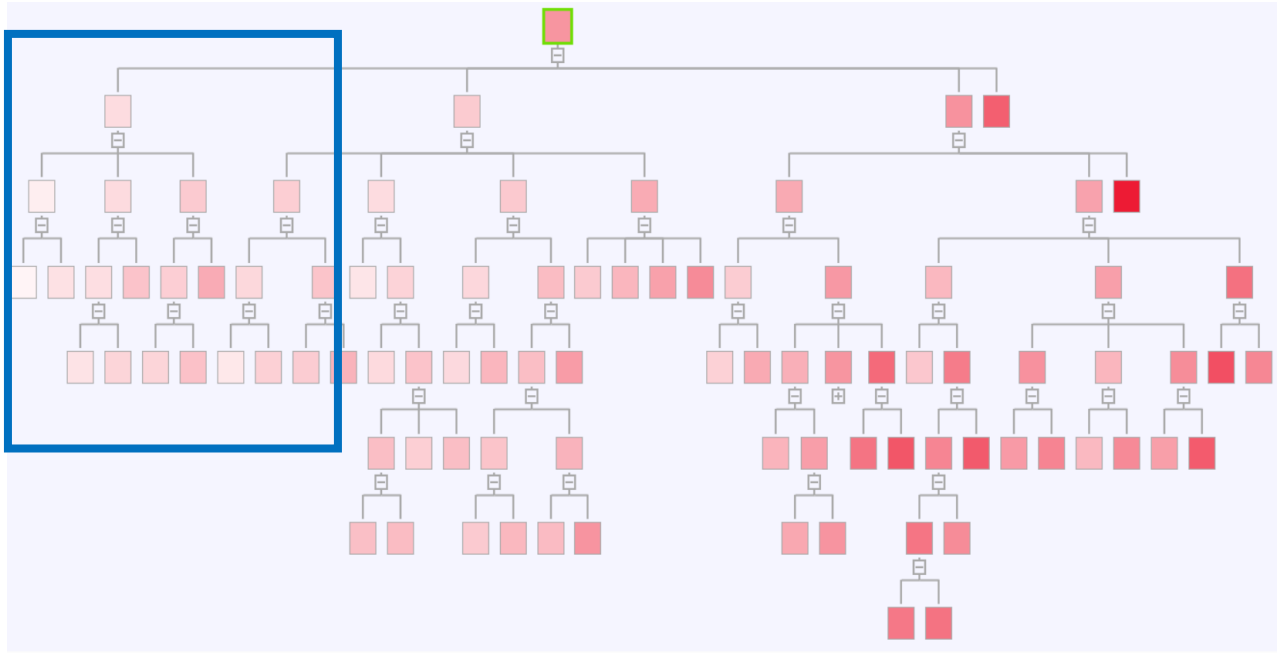
ALTAIR

Data Analysis

Analysis

Good Case

Bad Case



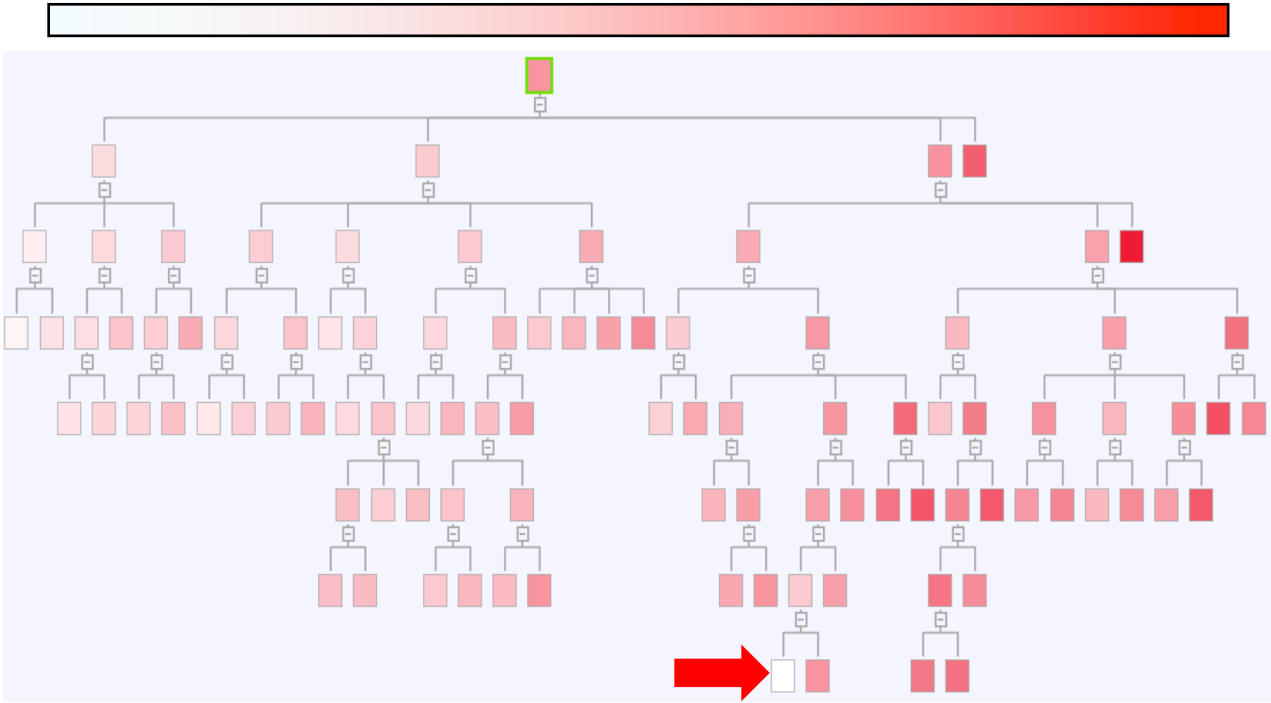
ALTAIR

Data Analysis

Analysis

Good Case

Bad Case



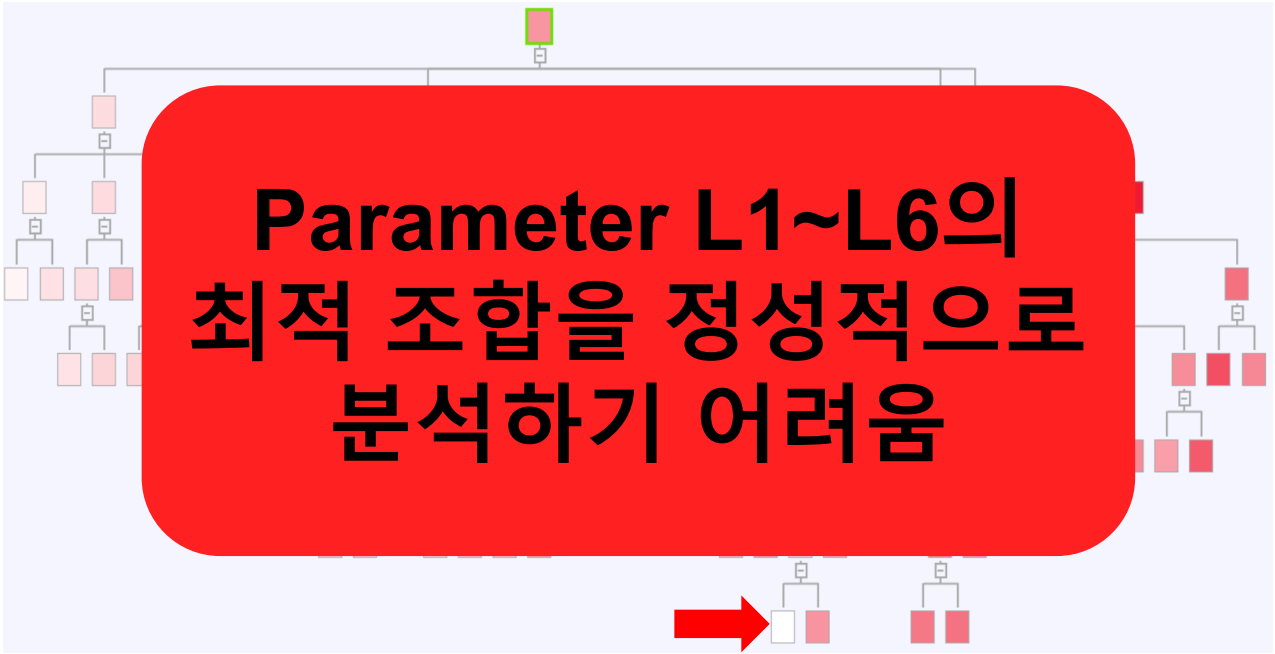
ALTAIR

Data Analysis

Analysis

Good Case

Bad Case



Parameter L1~L6의 최적 조합을 정성적으로 분석하기 어려움

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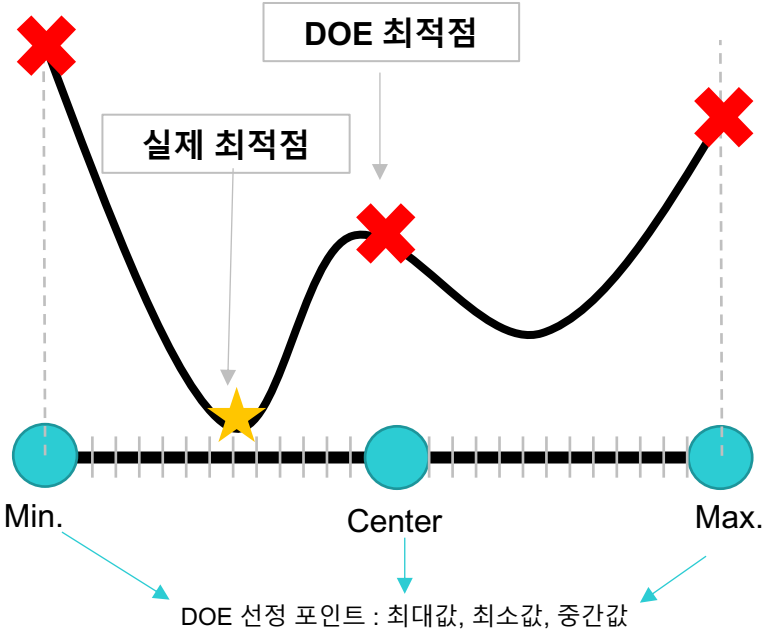
Data Analysis

Analysis



- ✓ 시간비용
- ✓ 정성적인 경향성 분석이 어려움

나머지 점의 최적해 탐색은?

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ARTIFICIAL NEURAL NETWORK

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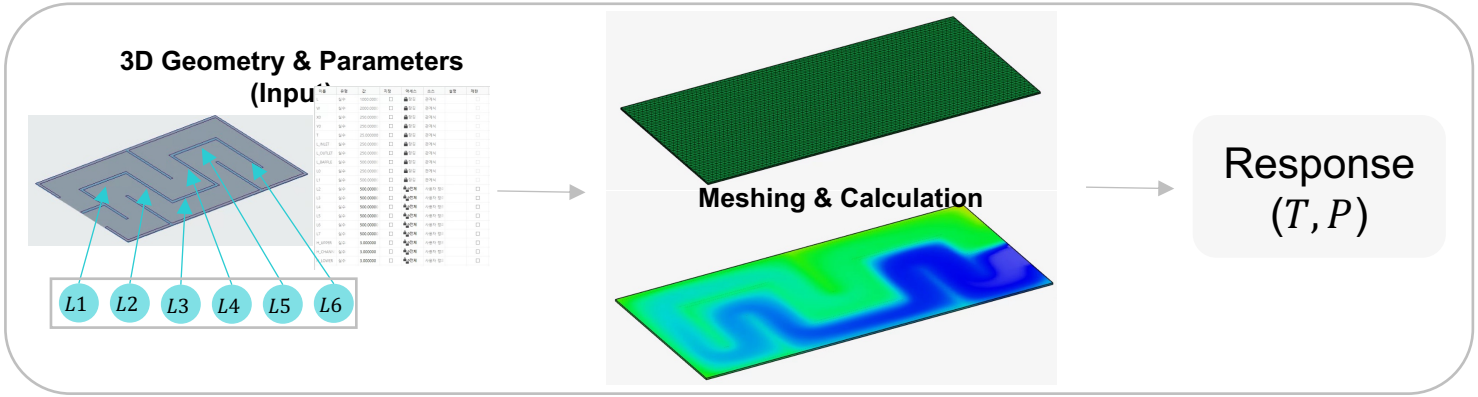
Artificial Neural Network

CFD & ANN

CFD



“입력” **“반복 계산”** **“출력”**

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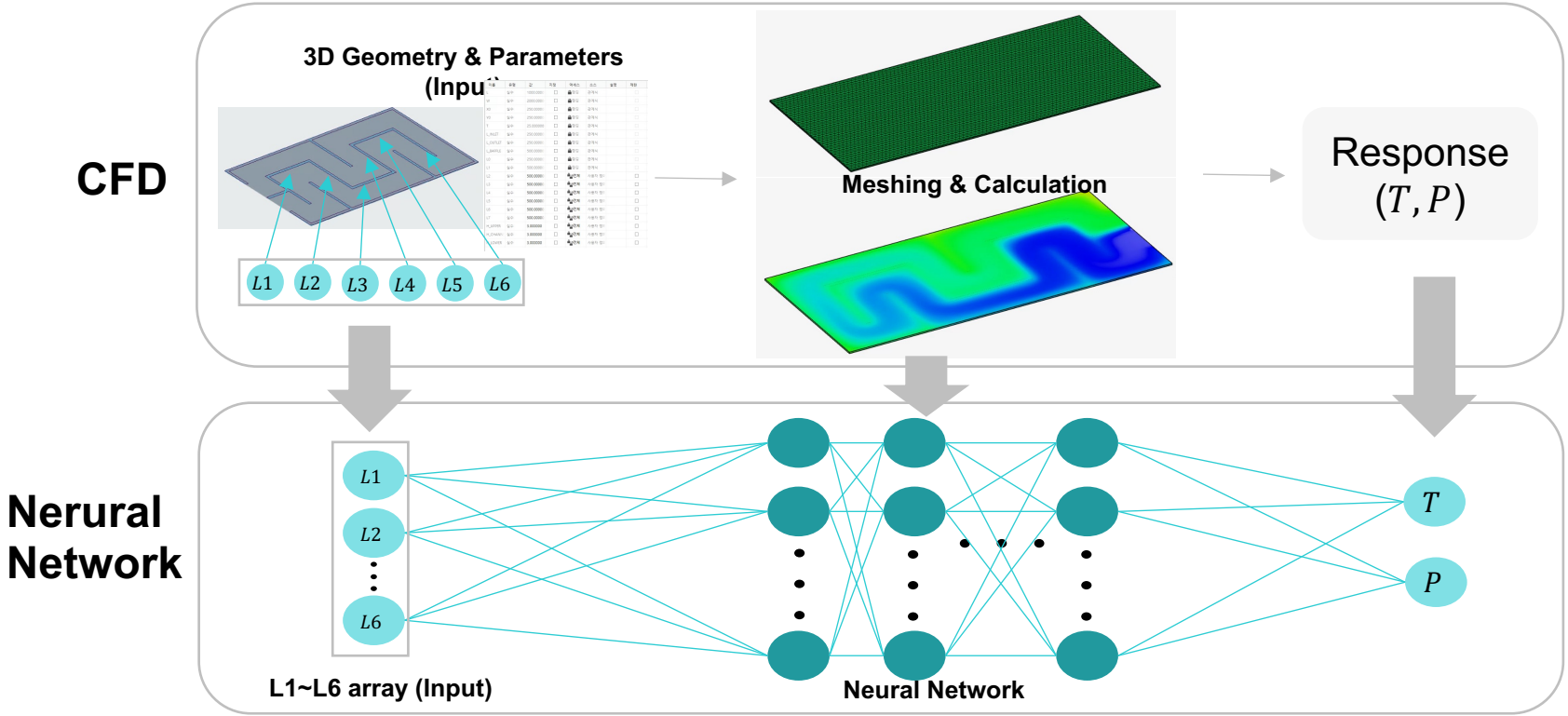
Artificial Neural Network

CFD & ANN



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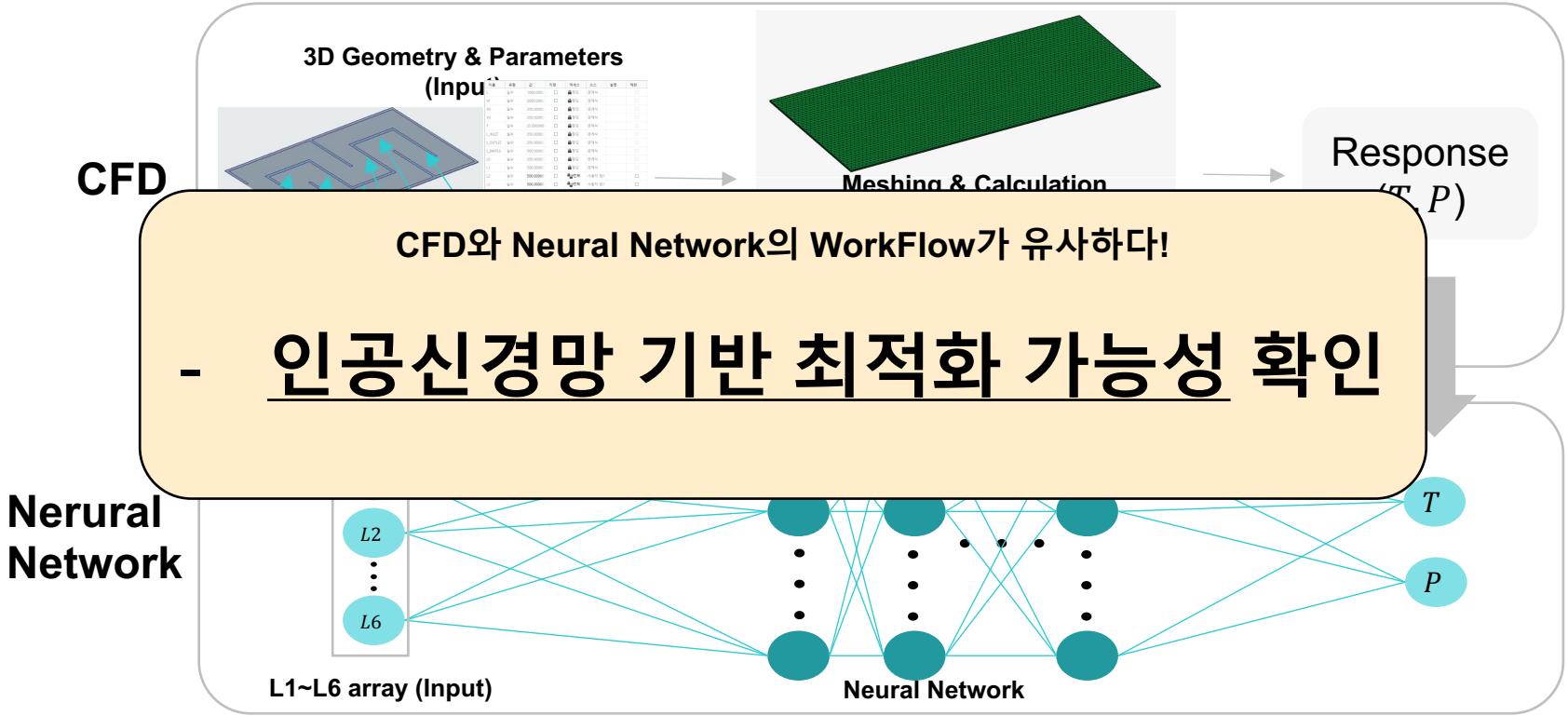
Artificial Neural Network

CFD & ANN



CFD와 Neural Network의 WorkFlow가 유사하다!

- **인공신경망 기반 최적화 가능성 확인**

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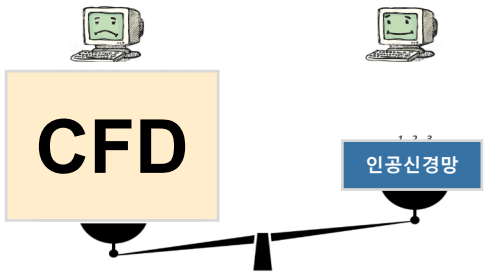
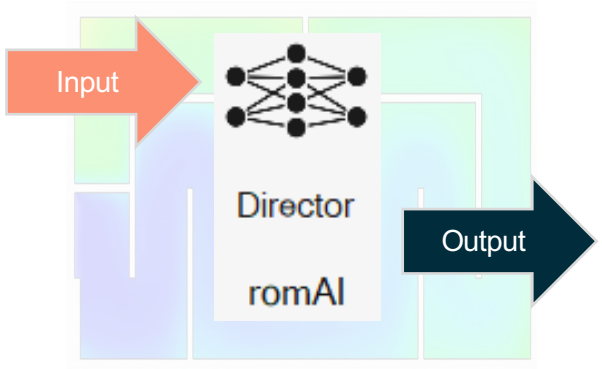
Artificial Neural Network

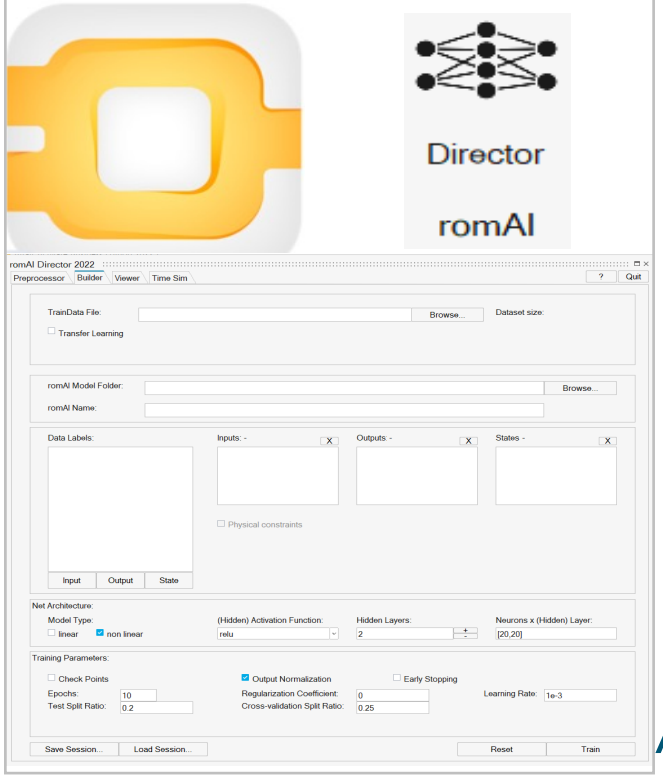
CFD & ANN

ROM (Reduced order model)





Altair Activate - romAI 기능



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Artificial Neural Network

Process

DOE 최적화 Process

729 개

L1~L6 → T, P
L1~L6 → T, P
L1~L6 → T, P
.
.
.

data729

인공신경망 최적화 Process

Training

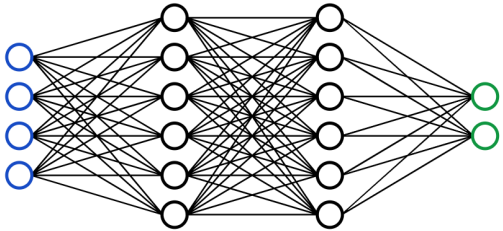
Dataset
(Train, Validation, Test)

Total Data

Train Data | Test Data

80% | 20%

인공신경망 학습



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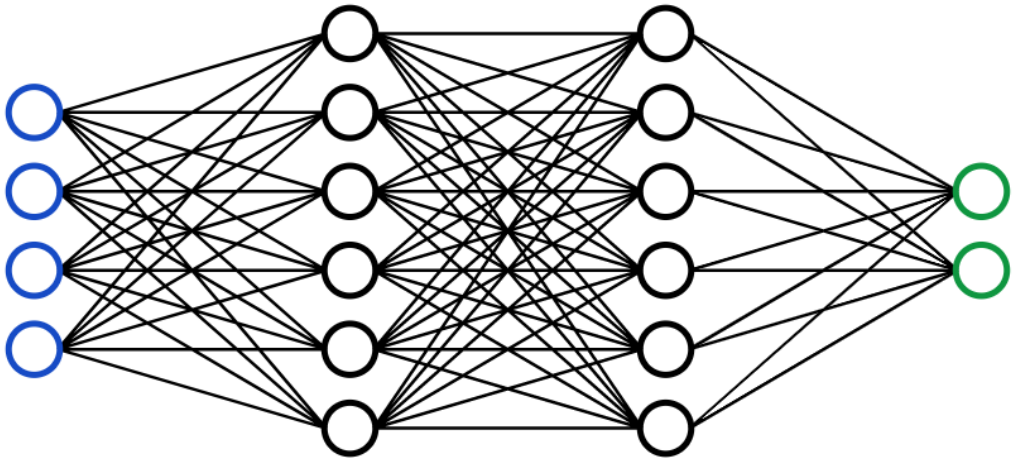
Artificial Neural Network

Process

Input

L1~L6 조합 생성 (10^6개)



Output

예측 결과 (T, P)

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Artificial Neural Network

Results

DOE

729 cases 해석 시간 : 43hours

→ 100# 당 해석 시간 : 5.9 hours **(21,240sec)**

인공신경망

1,000,000 cases 해석 시간 : 41 sec

→ 100# 당 해석 시간 : 4.1 ms **(41×10^{-4} sec)**

만약 DOE로 1,000,000 cases를 모두 해석한다면 걸리는 시간은?

"6.83 years"

인공신경망 - **계산 효율성↑**

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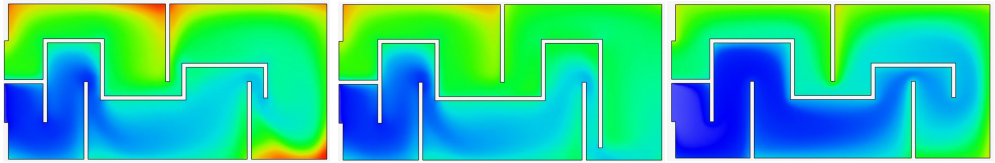
Artificial Neural Network

Results

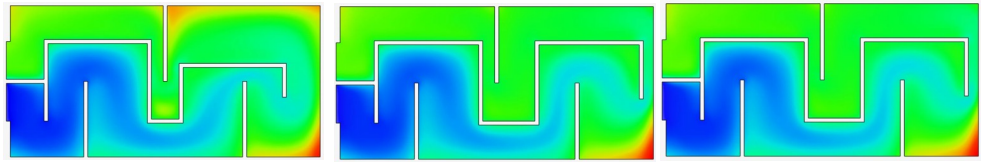
DOE

“Score” 개선된 모델 도출!

인공신경망



$\alpha = 0.3$		$\alpha = 0.5$		$\alpha = 0.7$	
$T_{avg}[\%]$	$P\ [\%]$	$T_{avg}[\%]$	$P\ [\%]$	$T_{avg}[\%]$	$P\ [\%]$
10.19	-7.0	6.30	-0.2	-2.17	12.0
Score : 95.90		Score : 97.03		Score : 99.52	



$\alpha = 0.3$		$\alpha = 0.5$		$\alpha = 0.7$	
$T_{avg}[\%]$	$P\ [\%]$	$T_{avg}[\%]$	$P\ [\%]$	$T_{avg}[\%]$	$P\ [Pa]$
9.36	-13.6	7.58	-5.2	5.29	-0.593
Score : 90.82		Score : 95.91		Score : 98.31	

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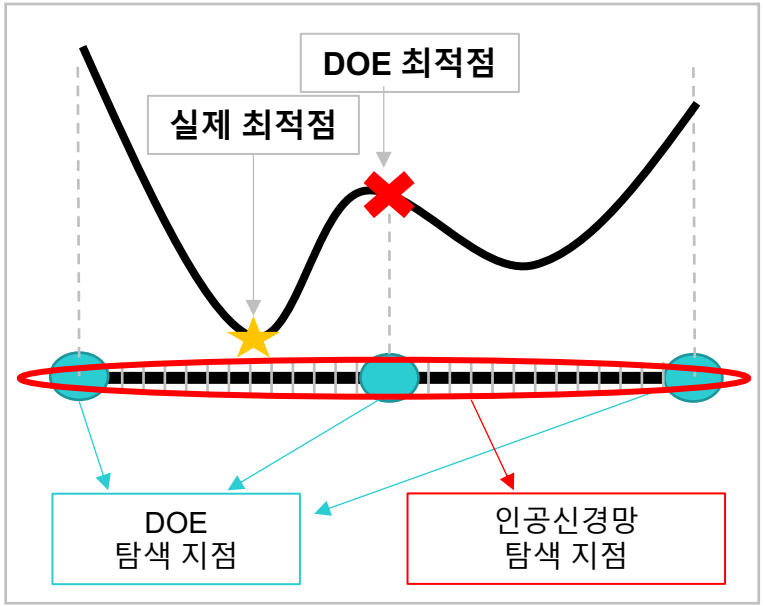
Artificial Neural Network

Results

DOE

인공신경망



인공신경망 – **탐색 수↑ & 최적점 탐색 가능성↑**

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CONCLUSIONS

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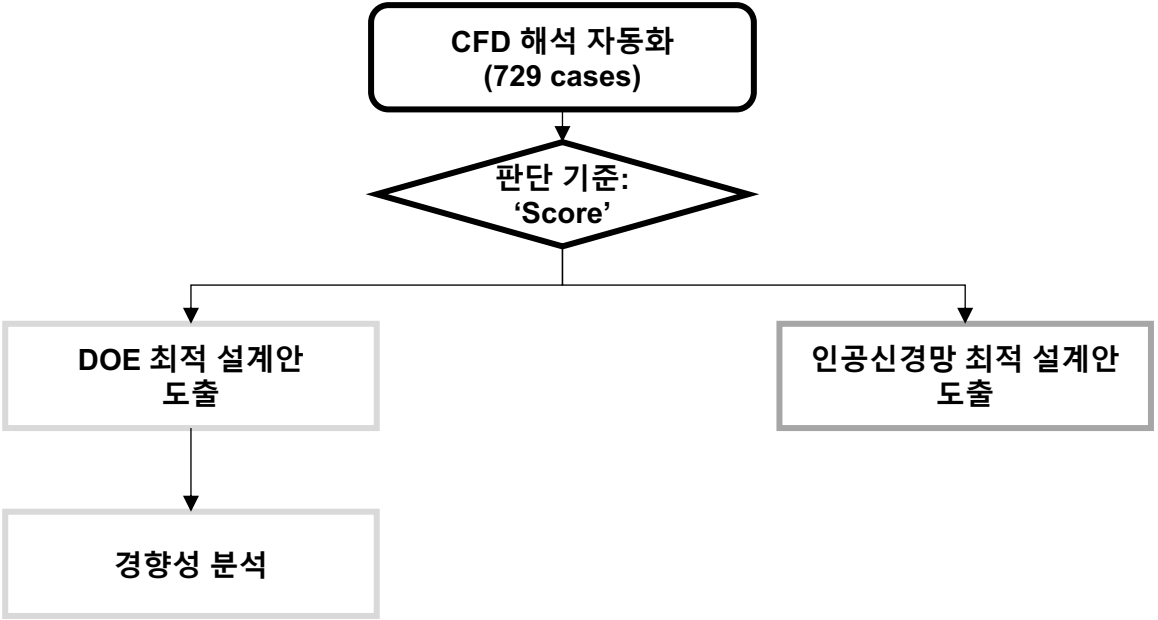
Conclusions

Summary



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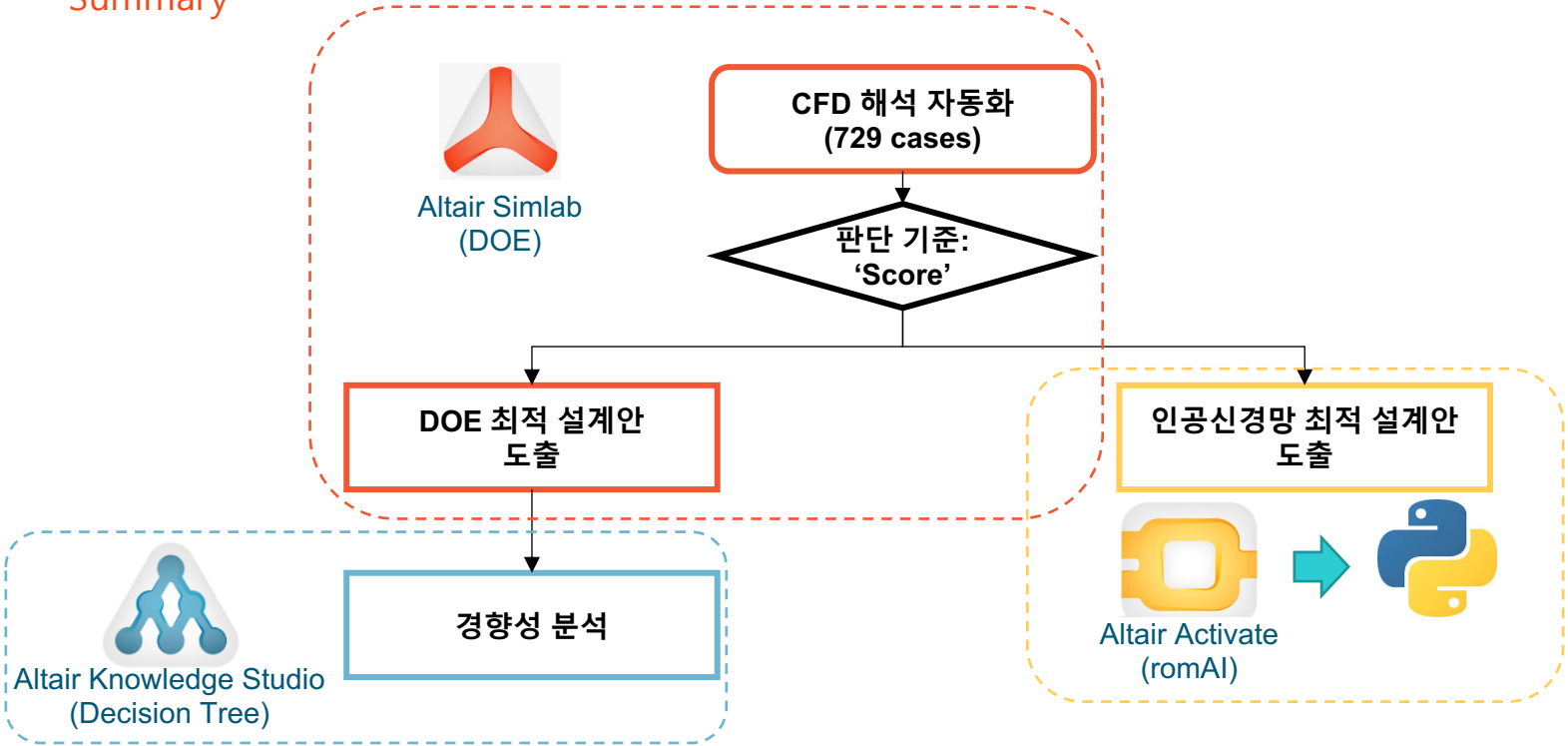
Conclusions

Summary



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Conclusions

Summary

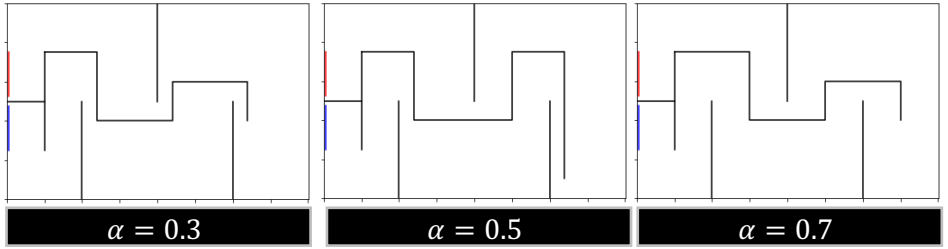
➢ **DOE 최적화** : 729개의 케이스 탐색
→ α = 0.3 일 때, 기존보다 **P 7%↓** score **4.1↓**
→ α = 0.5 일 때, 기존보다 **P 0.2%↓** score **2.97↓**
→ α = 0.7 일 때, 기존보다 **T 2.17%↓** score **0.48↓**

➢ **인공신경망 최적화** : 1,000,000개의 케이스 탐색
→ α = 0.3 일 때, 기존보다 **P 13.6%↓** score **9.18↓**
→ α = 0.5 일 때, 기존보다 **P 5.2%↓** score **4.09↓**
→ α = 0.7 일 때, 기존보다 **P 0.593%↓** score **1.69↓**

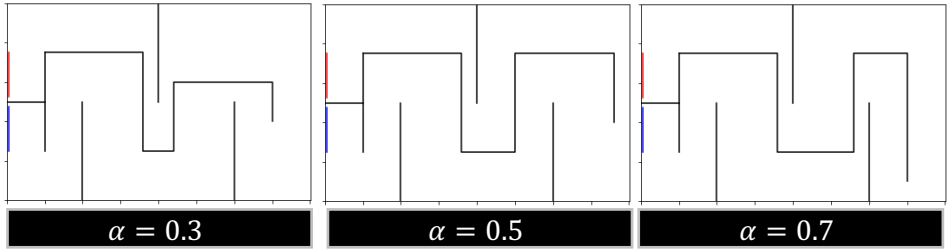
인공신경망으로 **보다 우수한 최적화** 결과 얻음

최적화 결과

DOE 최적화



인공신경망 최적화



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Conclusions

Conclusion

- ✓ **DOE optimization**
- ✓ **Data Generation** : “데이터 부족” 문제 해결
- ✓ **인공신경망** : 계산 효율성 ↑ → 계산비용 절감

→ **최적화 성능 ↑**

- ➢ **Engineering Design + AI**
- ➢ **미래지향적 기술 적용 가능성**
  (Design Automation, Digital Twin …)

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THANK YOU

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