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Convolutional Neural Network Applied Core Peaking Factor Analysis and Sensitivity Study for SMART Core

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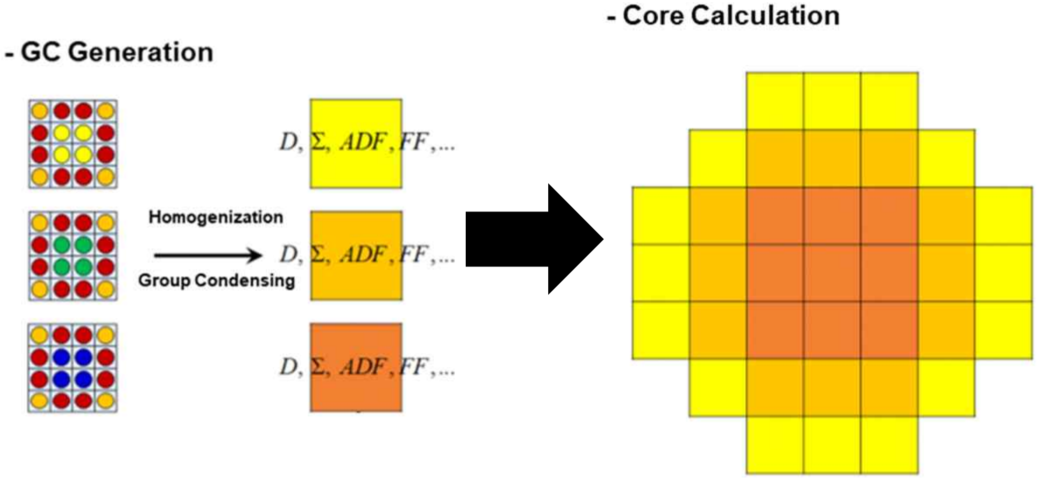
1. Introduction

- The existing two step method was divided into Group Constant(GC) generation with lattice code and Core Calculation with nodal code.
- A great deal of effort has been put into doing core analysis by solving transport or diffusion equations.



Two Step Method

1. Introduction

- In recent years, research on core analysis using deep learning like a **CNN** has been actively conducted.
  - Y.D. Nam, J. Y. Lee, H. J. Shim, "Convolutional Neural Network for BOC 3D Pin Power Prediction"
  - J. Y. Lee, Y. D. Nam, H. G. Joo, "Convolutional Neural Network for Power Distribution Prediction in PWRs"

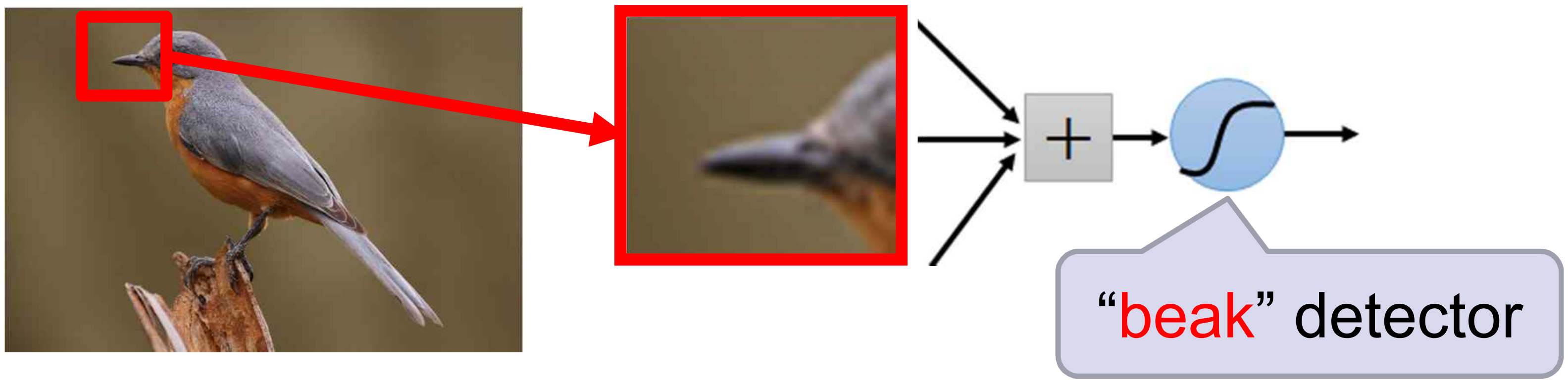
- A study on the **CNN core analysis of the SMART core**, a small modular reactor, was performed and results will be shown in this presentation.

2. Convolutional Neural Network Model

■ **Consider learning an image**

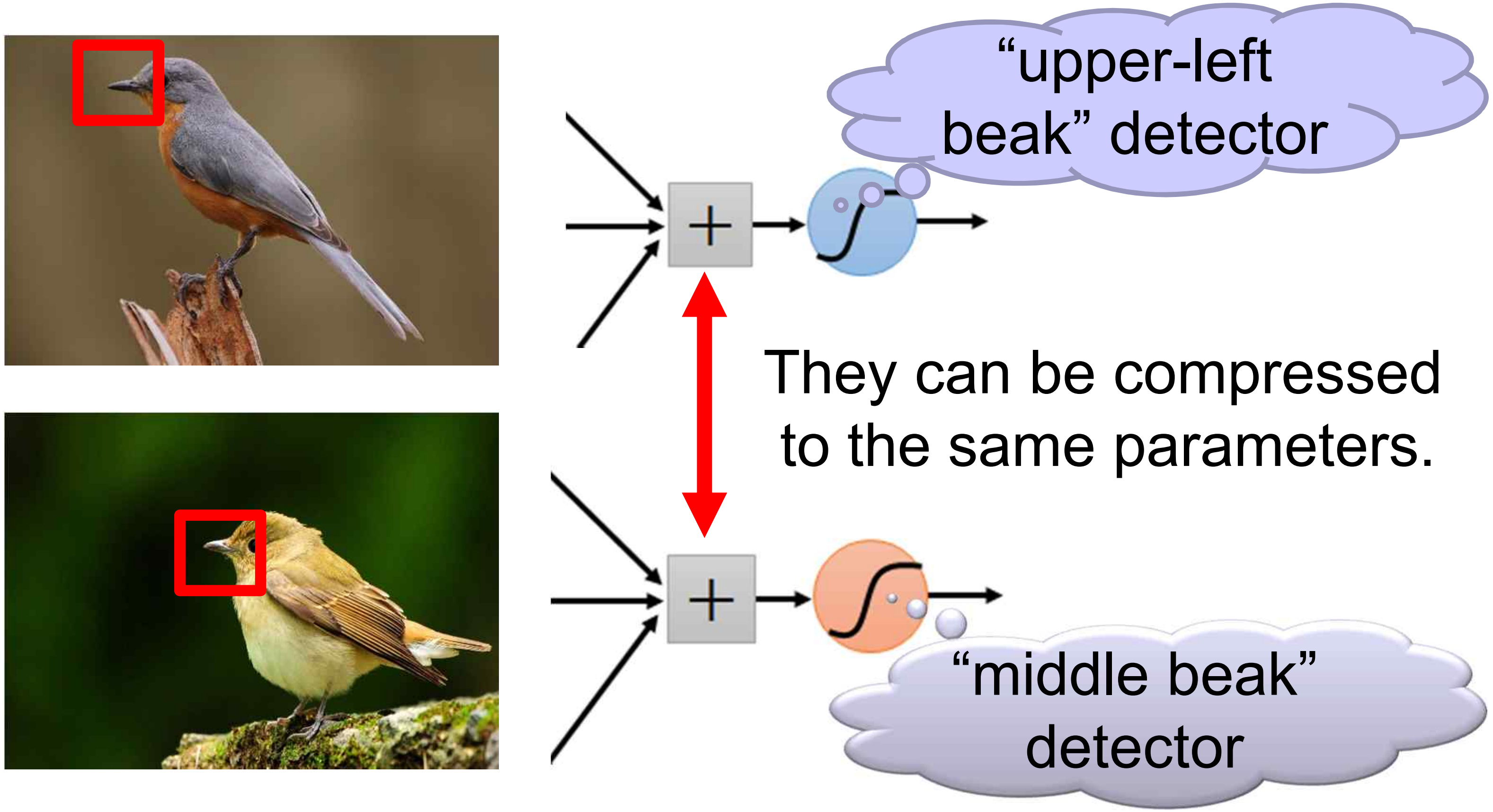
▶ **Some patterns are much smaller than the whole image**

Can represent a small region with fewer parameters



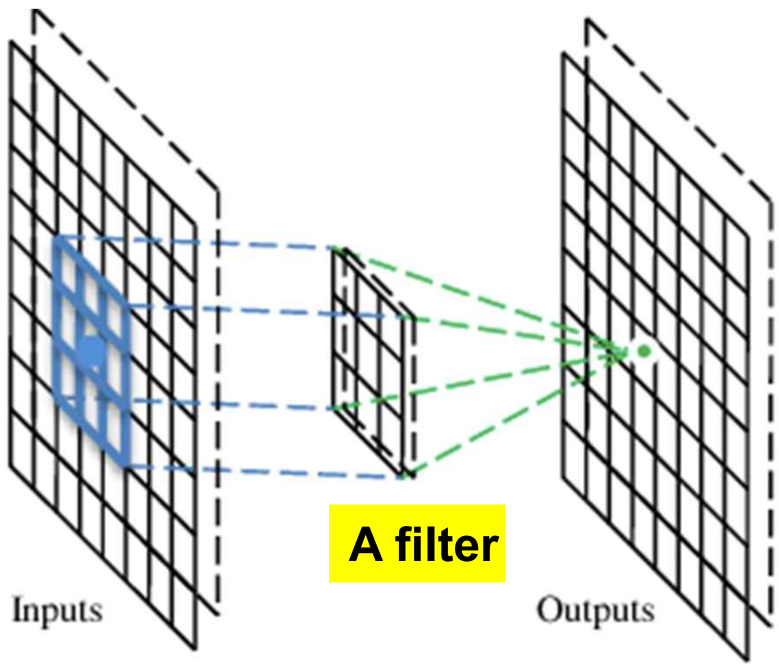
2. Convolutional Neural Network Model

- Same pattern appears in different places:
  They can be compressed!
- Small detectors and each detector must move around.



■ Convolutional Layer

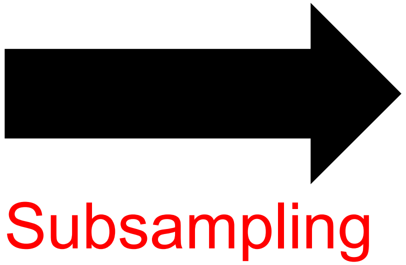
▶ A CNN is a neural network with some convolutional layers(and some other layers). A convolutional layer has a number of filters that does convolutional operation.



■ Pooling Layer

- ▶ Subsampling pixels will not change the object
- ▶ We can subsample the pixels to make image smaller fewer parameters to characterize the image

bird



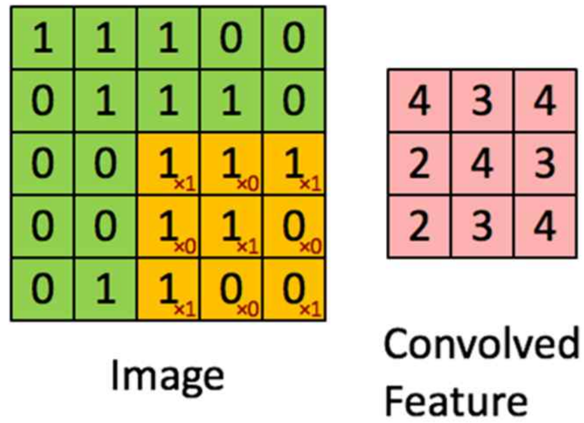
bird

2. Convolutional Neural Network Model

■ CNN(Convolution Neural Network) Model

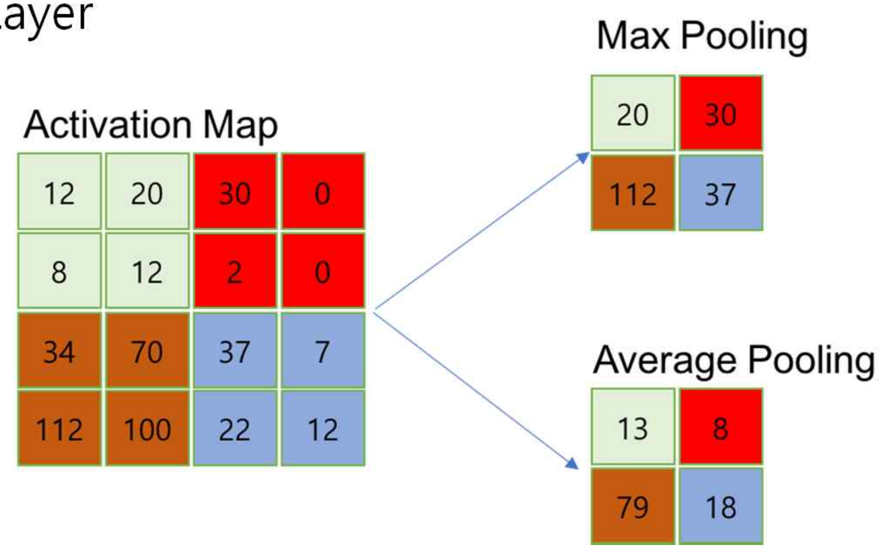
▶ Convolution Layer

- Image Input(Green), 3x3 Filter(Orange)
- Convolved Feature



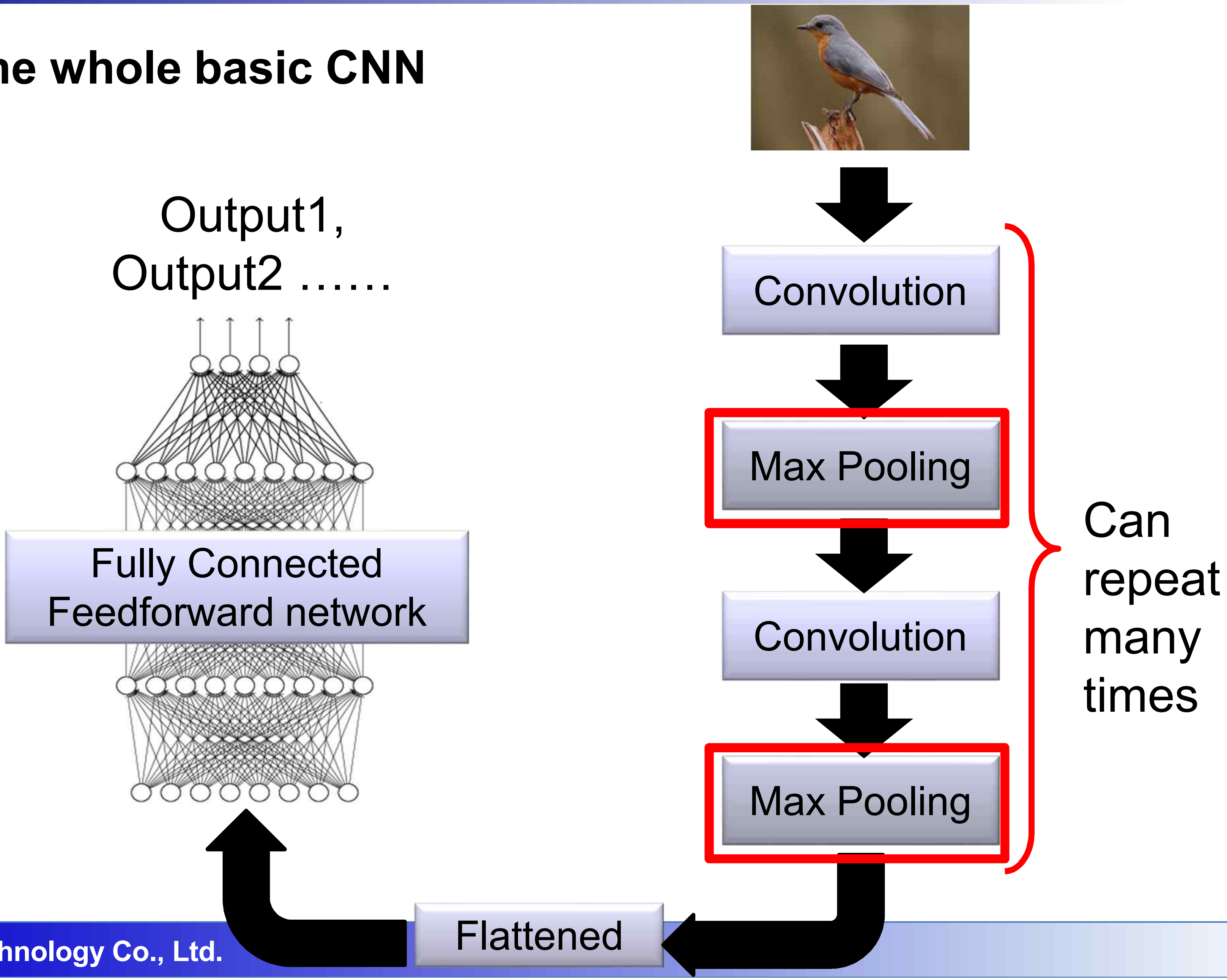
▶ Pooling Layer

- Extract Features with divided Layer
  - Max Pooling
  - Average Pooling



2. Convolutional Neural Network Model

■ **The whole basic CNN**

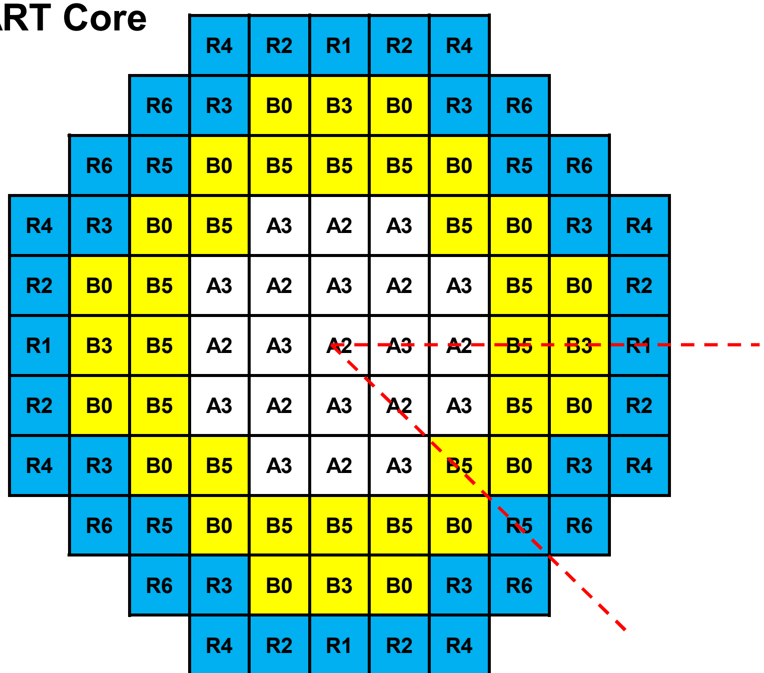


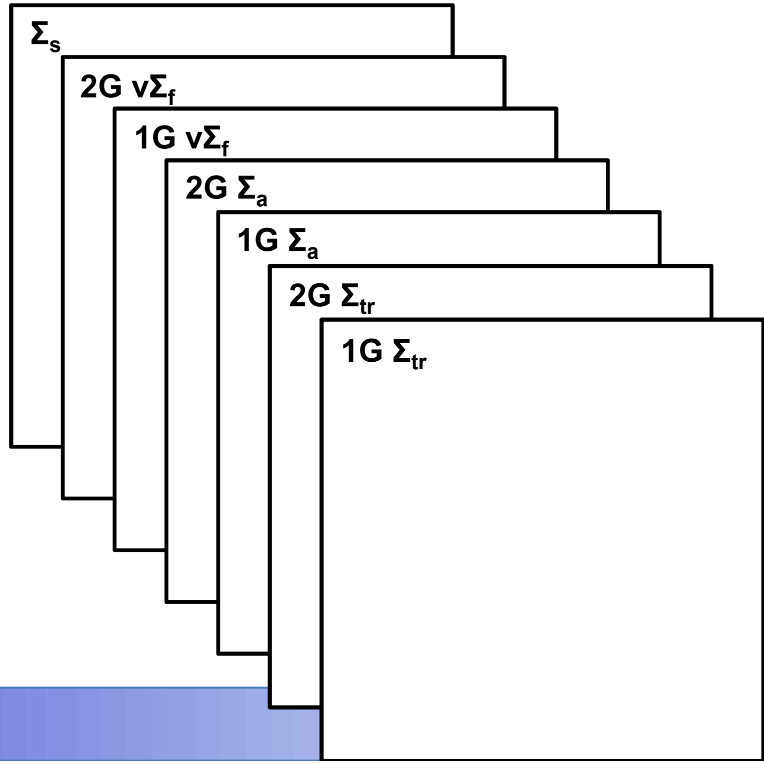
■ A CNN analysis for the SMART Core (Initial Core Condition)

▶ Composition of Training Data (MASTER XSL Used)

- Input : Loading Pattern, GC data for each FAs
  - Loading Pattern – Randomly generated with 1/8 symmetry LPs
  - GCs data for each FAs - Σ_{tr}, Σ_a, $\nu\Sigma_f$, Σ_s GCs data
    - 7 GCs depending on the energy group

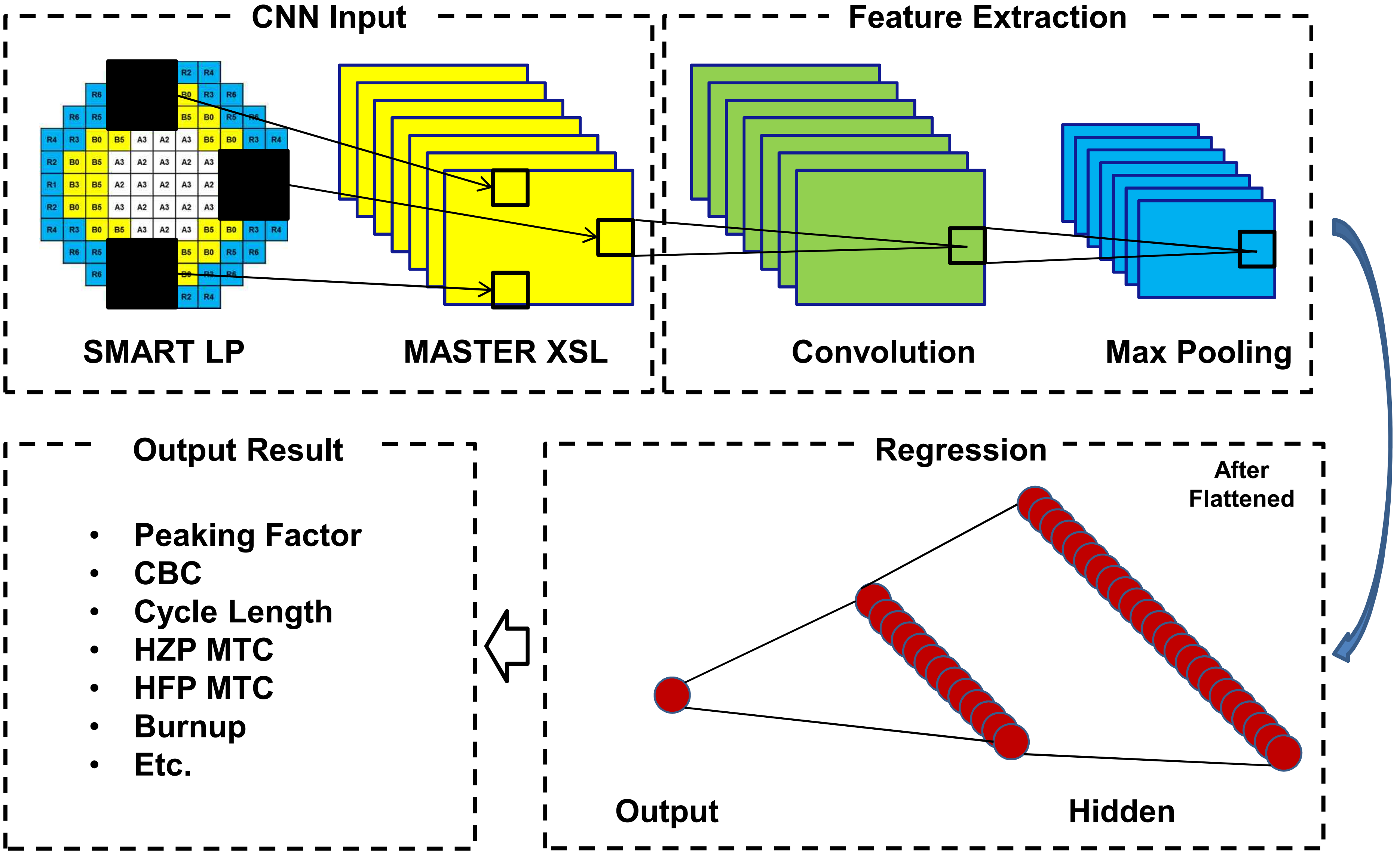
SMART Core





2. Convolutional Neural Network Model

■ SMART Core CNN Model



2. Convolutional Neural Network Model

■ Sensitivity Study for the Optimized CNN Model

▶ **Compare the loss values affected by the values(number of filters, number of layers and etc) used in the model**

# of Filters	Loss	# of CL	Loss
7	0.0700	1	-
14	0.0340	2	0.0357
21	0.0191	3	0.0315
28	0.0154	4	0.0054
35	0.0136	5	0.0053

# of FCL	Loss	Size of FCL	Loss
1	-	175	-
2	0.0347	350	0.0357
3	0.0314	525	0.0233
4	0.0272	700	0.0191
5	0.0242	875	0.0174

■ Optimized CNN Model

Layer	Output Shape	Param #
Conv. Layer 1	(11,11,35)	4235
Conv. Layer 2	(10,10,70)	7000
Conv. Layer 3	(9,9,105)	8505
Conv. Layer 4	(8,8,140)	8960
Max Pooling	(4,4,140)	2240
Flatten	(2240)	2240
FC Layer 1	(4480)	4480
FC Layer 2	(2240)	2240

<Loss Function>

Mean Squared Error (MSE) : MSE is a loss function widely used when operating deep learning models for regression purposes.

$$L = \frac{1}{2}\sum_{i=1}^{N}(y_i - t_i)^2$$

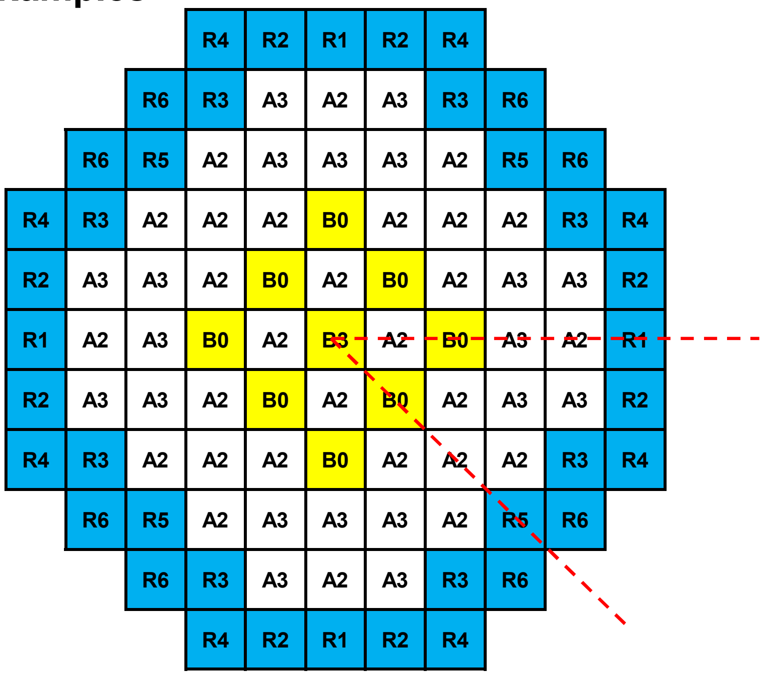
3. Verification Result for the SMART Core

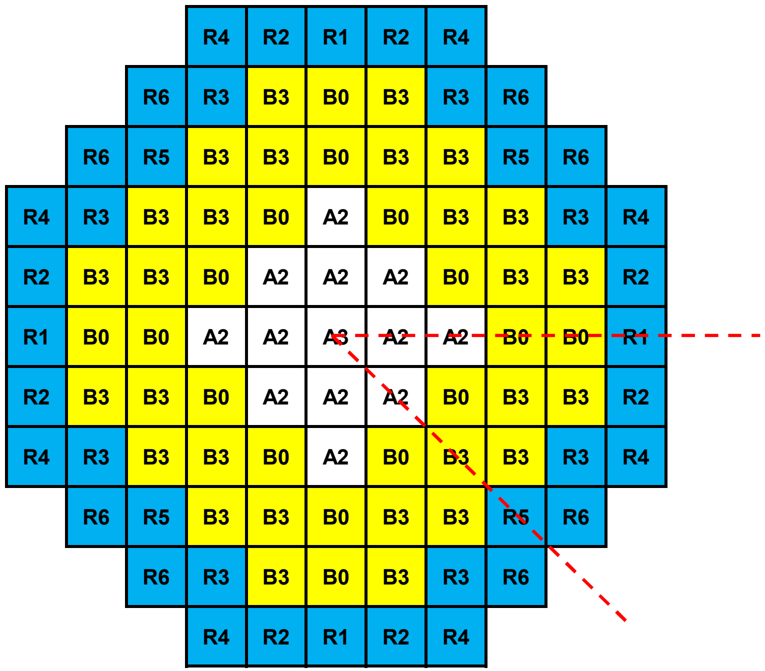
■ CNN Verification Result (SMART BOC)

▶ 1/8 Symmetry LPs (Train : 50,000/Test : 5,000)

- Σ_{tr}, Σ_a, $\nu\Sigma_f$, Σ_s GCs Data
- Training was performed with output F_r
  - Trained F_r Range - 1.21 ~ 6.71
  - Test F_r Range - 1.28 ~ 6.44

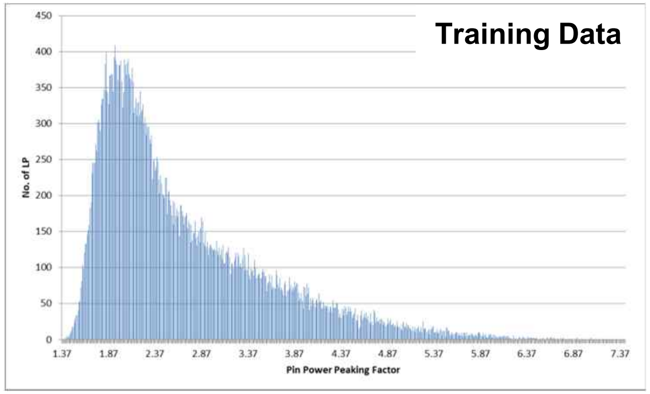
LP Examples

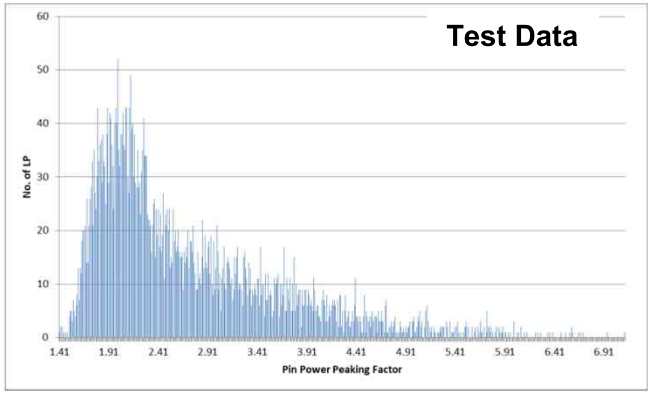




3. Verification Result for the SMART Core

■ Data Profile for the Training Data and Test Data





■ FRA Results

RMS Error	Max Error*	Average Error*	1% Excess Error*	3% Excess Error*
0.0156	4.03%	0.51%	6.86%	0.12%

*** Absolute Error**

■ Fr Results

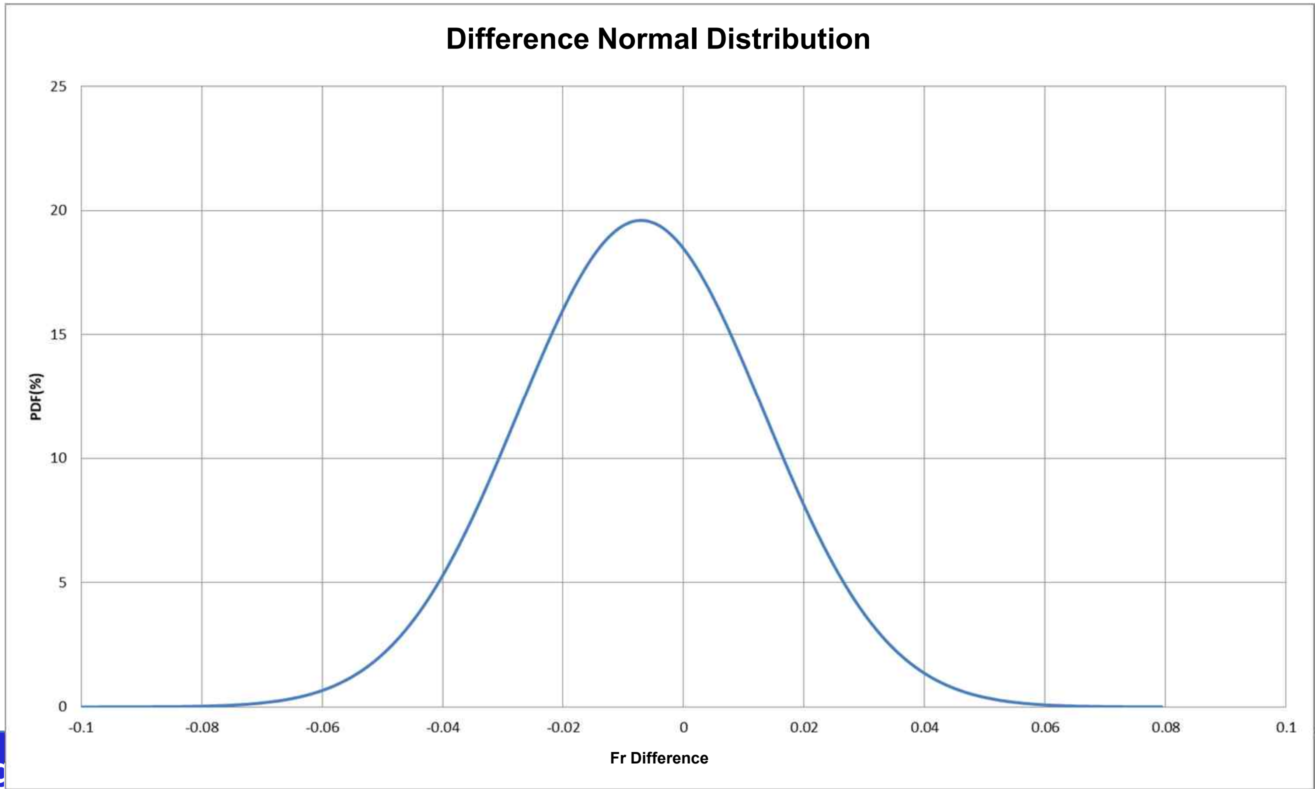
RMS Error	Max Error*	Average Error*	1% Excess Error*	3% Excess Error*
0.0148	3.91%	0.43%	6.40%	0.06%

*** Absolute Error**

3. Verification Result for the SMART Core

■ Fr difference distribution analysis

	Average	Stdev(σ)	+2σ Excess	-2σ Below
Fr	-0.0081	0.0096	2.54%	2.34%
			+3σ Excess	-3σ Below
			0.26%	0.44%



■ CNN Verification Result (SMART BOC)

▶ Asymmetric LPs (Train : 50,000/Test : 5,000)

- Σ_{tr}, Σ_a, $\nu\Sigma_f$, Σ_s GCs Data
- Training was performed with output F_r
  - Trained F_r Range - 1.78 ~ 7.29
  - Test F_r Range - 2.04 ~ 6.44

LP Examples

			R4	R2	R1	R2	R4			
		R6	R3	A3	A2	A3	R3	R6		
	R6	R5	A2	A3	A3	A3	A2	R5	R6	
R4	R3	A2	A2	A2	B0	2	A2	A2	R3	R4
R2	A3	A3	A2	B0	A2	B0	A2	A3	A3	R2
R1	A2	A3	B0	A2	B3	A2	B0	A3	A2	R1
R2	A3	A3	A2	B0	A2	B0	A2	A3	A3	R2
R4	R3	A2	A2	A2	B0	A2	A2	A2	R3	R4
	R6	R5	A2	A3	A3	A3	A2	R5	R6	
		R6	R3	A3	A2	A3	R3	R6		
			R4	R2	R1	R2	R4			

			R4	R2	R1	R2	R4			
		R6	R3	B3	B0	B3	R3	R6		
	R6	R5	B3	B3	B0	B3	B3	R5	R6	
R4	R3	B3	B3	B0	A2	B0	B3	B3	R3	R4
R2	B3	B3	B0	A2	A2	A2	B0	B3	B3	R2
R1	B0	B0	A2	A2	A3	A2	A2	B0	B0	R1
R2	B3	B3	B0	A2	A2	A2	B0	B3	B3	R2
R4	R3	B3	B3	B0	A2	B0	B3	B3	R3	R4
	R6	R5	B3	B3	B0	B3	B3	R5	R6	
		R6	R3	B3	B0	B3	R3	R6		
			R4	R2	R1	R2	R4			

3. Verification Result for the SMART Core

■ Fr Results

Max Error*	Average Error*	1% Excess Error*	3% Excess Error*
28.77%	4.31%	84.38%	55.94%

*** Absolute Error**

■ Feasible Range Analysis

▶ F_r Range - 2.04~3.00

▶ Train Data : 10,059 / Test Data : 1,036

Max Error*	Average Error*	1% Excess Error*	3% Excess Error*
12.35%	1.45%	18.23%	11.71%

*** Absolute Error**

4. Summary

- **Convolutional neural networks (CNN) were applied in the prediction of the pin power peaking factor of SMART core at initial core condition.**

- **The results show that the pin power peaking factor can be accurately predicted with very high computational efficiency.**
  - ▶ **The error in the maximum pin power peaking factor at the region of interest was less than 3%.**

- **But it is possible to predict only for the similar core shape and data with which it has been trained. Therefore, reinforcement learning and self-learning functions are required for new core shape and data.**

THANK YOU

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