

Cloud-Based Generative-AI Supporting Preliminary Engineering Design

Ameri, Nima – Rolls-Royce, Civil DigITal Advanced Analytics

Babu, Shiva - Rolls-Royce, SS&CE,Design Systems

Gurbani, Yashwant – Rolls-Royce, SS&CE,Design Systems

Nunez, Marco – Rolls-Royce, SS&CE,Design Systems

Ravichandran, Siddharth – Rolls-Royce, Civil DigITal Advanced Analytics

Adriaenssens Marjorie – Databricks,

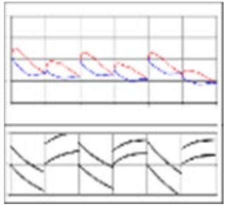
Jain, Puneet - Databricks

Jun 2024

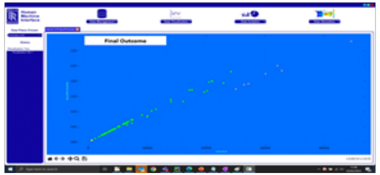
Content

Context & Motivation

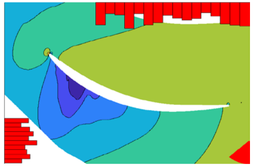
Multi-Fidelity Tools



Numerical Methods

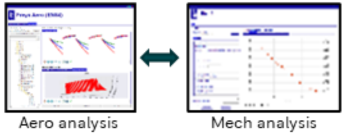


Machine Learning (cGAN)

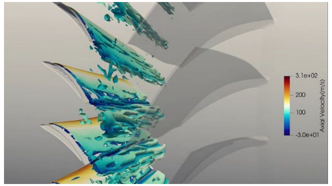


Preliminary concept definition → Full concept definition → Product Realisation → Production → In-Service support

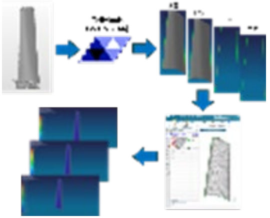
Preliminary Design



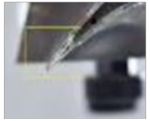
Detailed Design



Scan processing



Damage identification

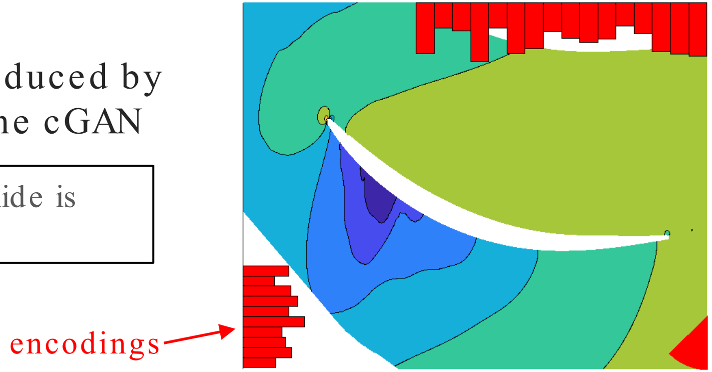


Conditional Generative Adversarial Networks (cGAN):

What is a cGAN

- Neural network used for generating realistic text, audio, images or video
- Consists of two neural networks - generator and discriminator
- Training process
  1. Train generator and discriminator using a 'real' dataset
  2. Generator creates item
  3. Discriminator decides if it is a 'real' item, or made by the generator
  4. Generator and discriminator learn from the outcome and adjust model
- Eng tool developed in MATLAB by the University of Southampton
- The encoded images** produced by the encoder are fed into the cGAN

** The IP described on this slide is protected by patent.



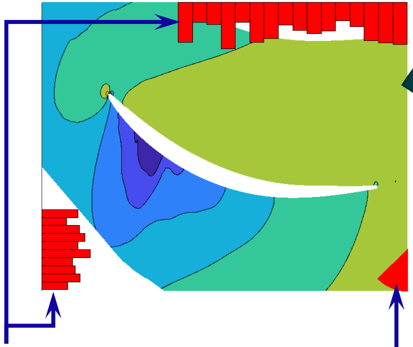
- cGANs thus offer an alternative to expensive simulations, with a prediction accuracy R^2 of up to 97%

Conditional Generative Adversarial Networks (cGAN*):

Benefits over conventional workflows

* Andy J. Keane and Ivan I. Voutchkov, Embedded Parameter Information in Conditional Generative Adversarial Networks for Compressor Airfoil Design, AIAA, 4 Aug 2022.

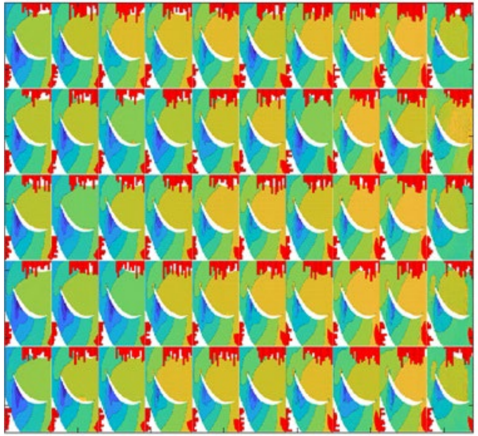
Parameter Encoded Image Input (from test or analysis)



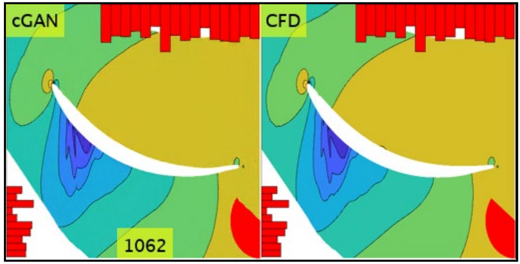
Encoded Geometric and Variability Parameters

Encoded Output Parameter

Training

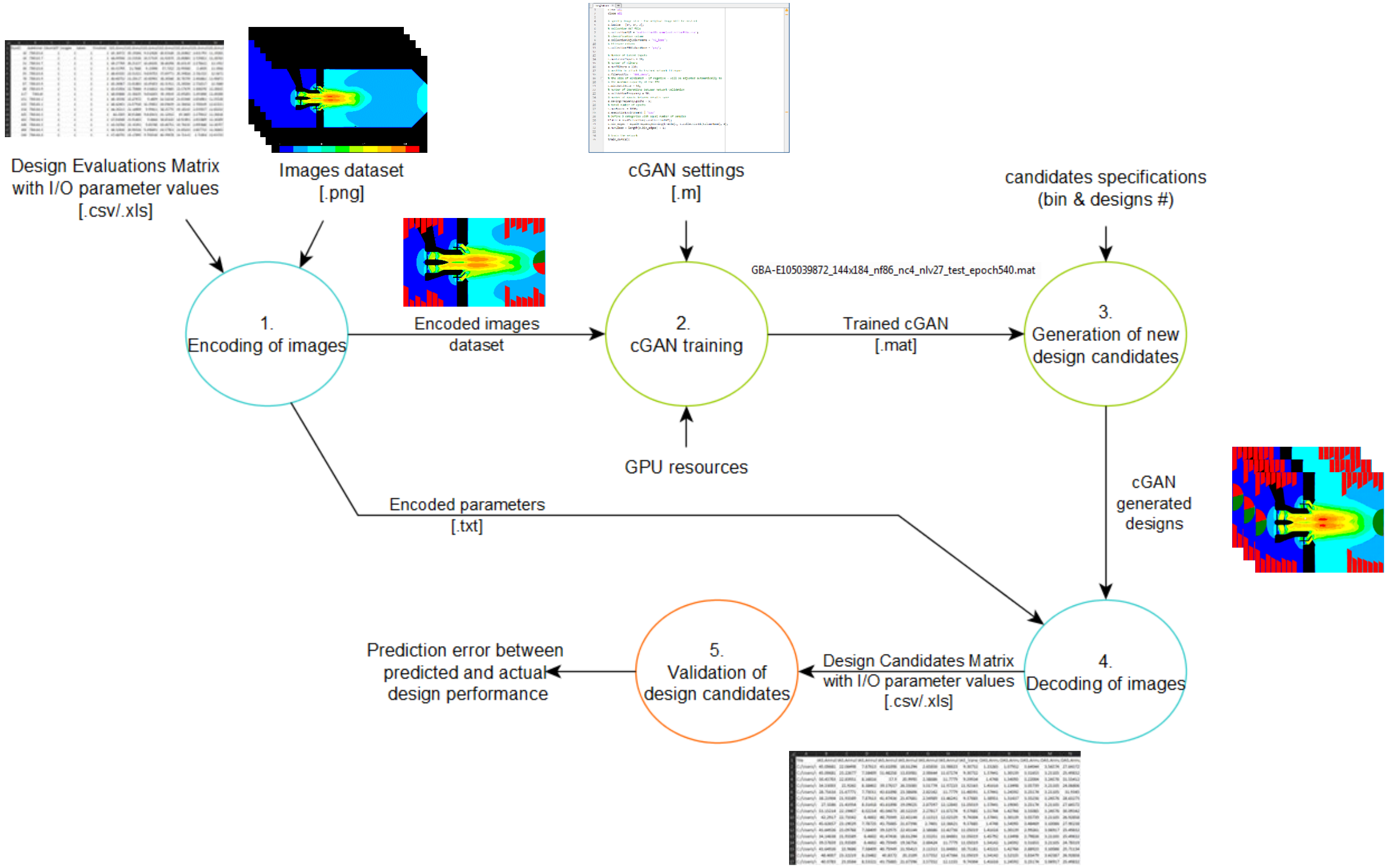


cGAN Output

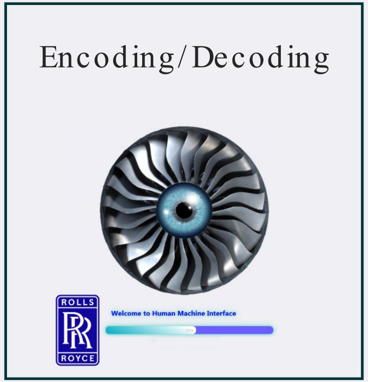


A set of possible geometries that fall within the performance parameter of interest range (i.e. Loss Coefficient).

Methodology



System prototype within Rolls-Royce: Encoding

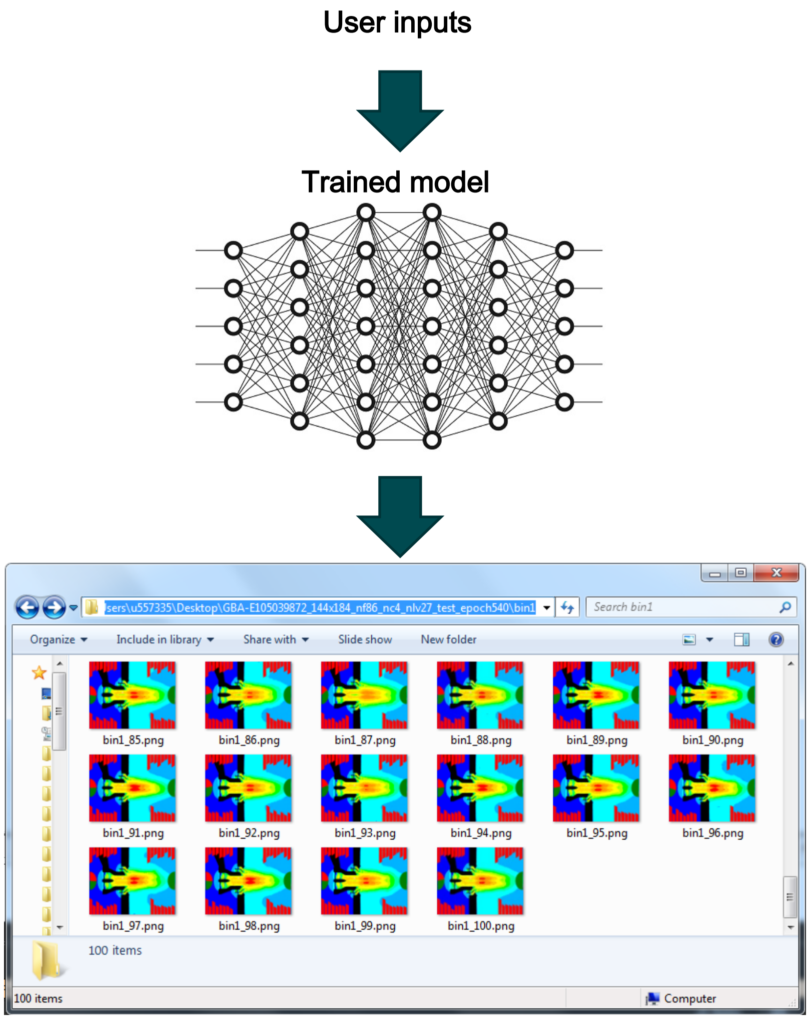


- Encoding Images: Method used to embed a set of specific input/output parameters chosen by the user into an image.
- Utilises 'real' design images with design parameters to then encode these into the image in contrasting bar charts

Output parameter encoding

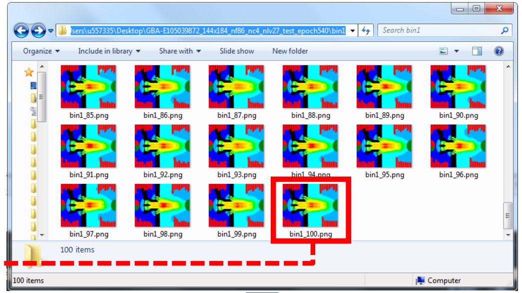
System prototype within Rolls-Royce:

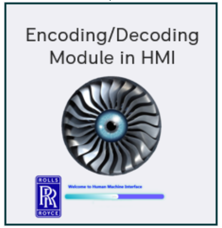
Prediction extraction

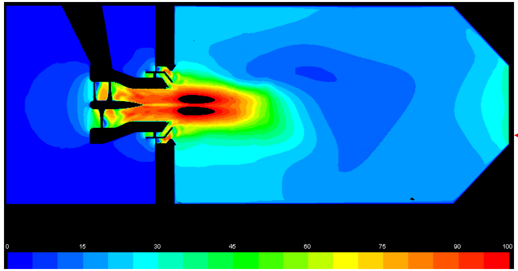


System prototype within Rolls-Royce: Decoding & Validation

Example







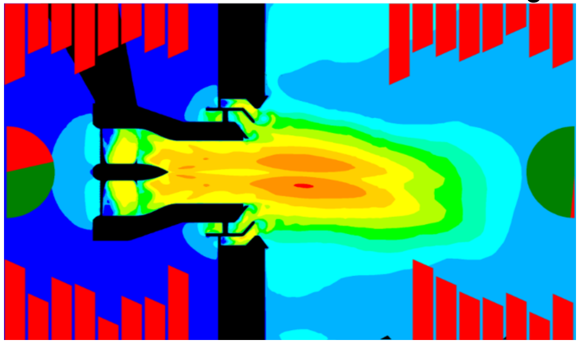
Validation through CFD

file	IAS.Annulus.IAS_Annulus_Inlet_Angle	IAS.Annulus.IAS_Annulus_Length	IAS.Annulus.IAS_Annulus_Out
C:/Users/u557335/Desktop/GBA-E105039872_144x184_nf86_nc4_nlv27_test_epoch540/bin1\decoded_bin1_1.txt	45.00681	22.06498	7.87
C:/Users/u557335/Desktop/GBA-E105039872_144x184_nf86_nc4_nlv27_test_epoch540/bin1\decoded_bin1_10.txt	45.00681	23.22677	7.58
C:/Users/u557335/Desktop/GBA-E105039872_144x184_nf86_nc4_nlv27_test_epoch540/bin1\decoded_bin1_100.txt	50.43703	22.83951	8.16
C:/Users/u557335/Desktop/GBA-E105039872_144x184_nf86_nc4_nlv27_test_epoch540/bin1\decoded_bin1_11.txt	34.53003	22.9265	8.38
C:/Users/u557335/Desktop/GBA-E105039872_144x184_nf86_nc4_nlv27_test_epoch540/bin1\decoded_bin1_12.txt	28.71616	21.67771	7.73
C:/Users/u557335/Desktop/GBA-E105039872_144x184_nf86_nc4_nlv27_test_epoch540/bin1\decoded_bin1_13.txt	38.21904	21.93589	7.87
C:/Users/u557335/Desktop/GBA-E105039872_144x184_nf86_nc4_nlv27_test_epoch540/bin1\decoded_bin1_14.txt	27.3586	21.41954	8.31
C:/Users/u557335/Desktop/GBA-E105039872_144x184_nf86_nc4_nlv27_test_epoch540/bin1\decoded_bin1_15.txt	53.15214	22.19407	8.02
C:/Users/u557335/Desktop/GBA-E105039872_144x184_nf86_nc4_nlv27_test_epoch540/bin1\decoded_bin1_16.txt	42.2917	22.71042	8.4
C:/Users/u557335/Desktop/GBA-E105039872_144x184_nf86_nc4_nlv27_test_epoch540/bin1\decoded_bin1_17.txt	45.62657	23.19029	7.78
C:/Users/u557335/Desktop/GBA-E105039872_144x184_nf86_nc4_nlv27_test_epoch540/bin1\decoded_bin1_18.txt	43.64926	23.09768	7.58
C:/Users/u557335/Desktop/GBA-E105039872_144x184_nf86_nc4_nlv27_test_epoch540/bin1\decoded_bin1_19.txt	34.14638	21.93589	8.4
C:/Users/u557335/Desktop/GBA-E105039872_144x184_nf86_nc4_nlv27_test_epoch540/bin1\decoded_bin1_2.txt	39.57659	21.93589	8.4
C:/Users/u557335/Desktop/GBA-E105039872_144x184_nf86_nc4_nlv27_test_epoch540/bin1\decoded_bin1_20.txt	43.64926	22.9686	7.58
C:/Users/u557335/Desktop/GBA-E105039872_144x184_nf86_nc4_nlv27_test_epoch540/bin1\decoded_bin1_21.txt	48.4007	23.32219	8.23
C:/Users/u557335/Desktop/GBA-E105039872_144x184_nf86_nc4_nlv27_test_epoch540/bin1\decoded_bin1_22.txt	40.0783	23.0584	8.53
C:/Users/u557335/Desktop/GBA-E105039872_144x184_nf86_nc4_nlv27_test_epoch540/bin1\decoded_bin1_23.txt	47.72192	22.83951	8.16
C:/Users/u557335/Desktop/GBA-E105039872_144x184_nf86_nc4_nlv27_test_epoch540/bin1\decoded_bin1_24.txt	40.0783	23.19029	7.78

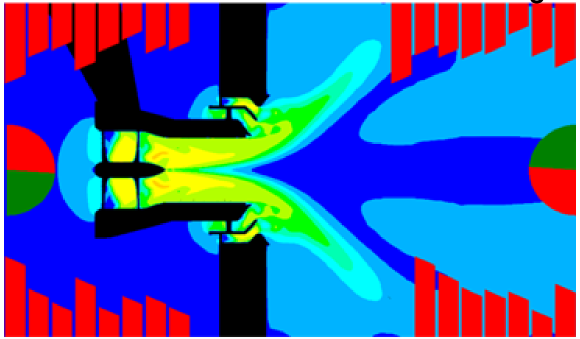
Use cases:

Fuel Spray Nozzle design

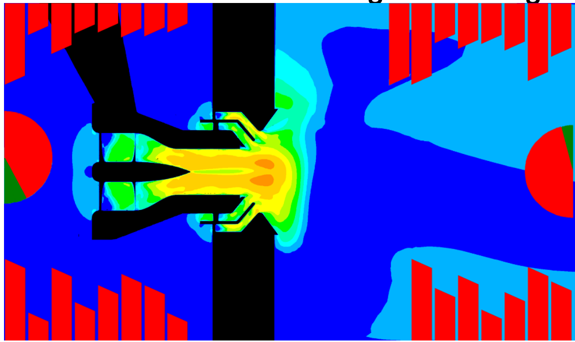
Low Cone Angle



Medium Cone Angle

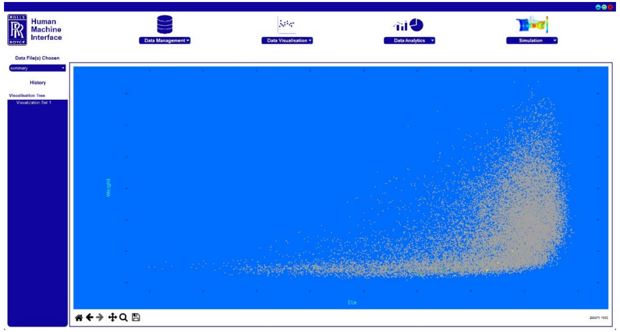


High Cone Angle

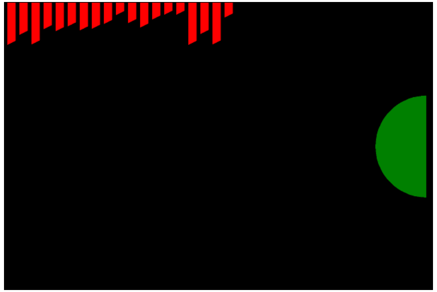


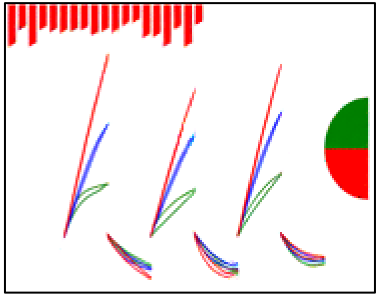
Use cases:

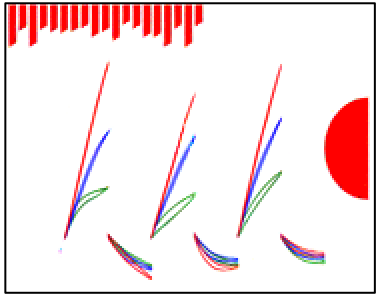
Multi-stage fan design use case



RunID	Input_01	Input_02	Input_03	Input_04	Input_05	Input_06	Input_07	Input_08	...	...	Output_01	Output_02	Output_03	Output_04	Output_05	Output_06	...	...	Cat	png
234334	0.656347	0.003607	0.3331	0.458652	0.288152	0.115767	0.832311	0.40612	...	...	NaN	NaN	NaN	NaN	NaN	NaN	...	...	0	Freya_blade234334.png
1720	0.37942	0.323757	0.834666	0.798851	0.630982	0.155926	0.313283	0.756547	...	...	0.315314	0.970736	0.383497	0.011575	0.038996	0.767998	...	...	1	Freya_blade1720.png
146243	0.977694	0.930069	0.325542	0.409584	0.266261	0.68781	0.886278	0.344856	...	...	0.7118	0.049582	0.092973	0.489507	0.152489	0.118435	...	...	2	Freya_blade146243.png
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...





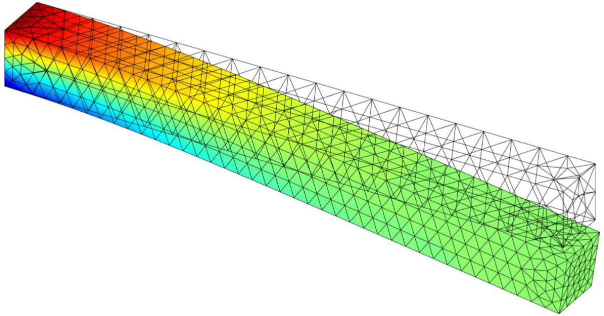


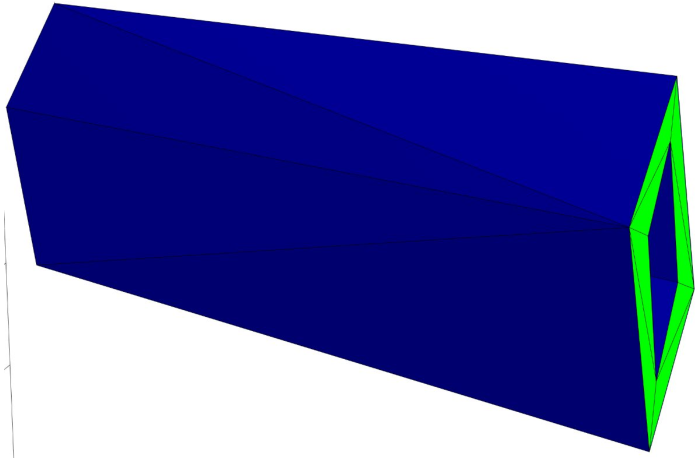
Use cases:

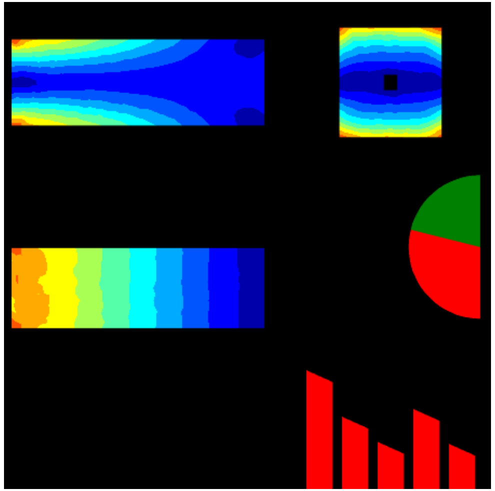
Cantilever Beam

Key challenges:

- Higher-GPU resources
- Scalability (fidelity &dimensionality)
- Configuration (hyperparameters)
- Computational time Vs costs

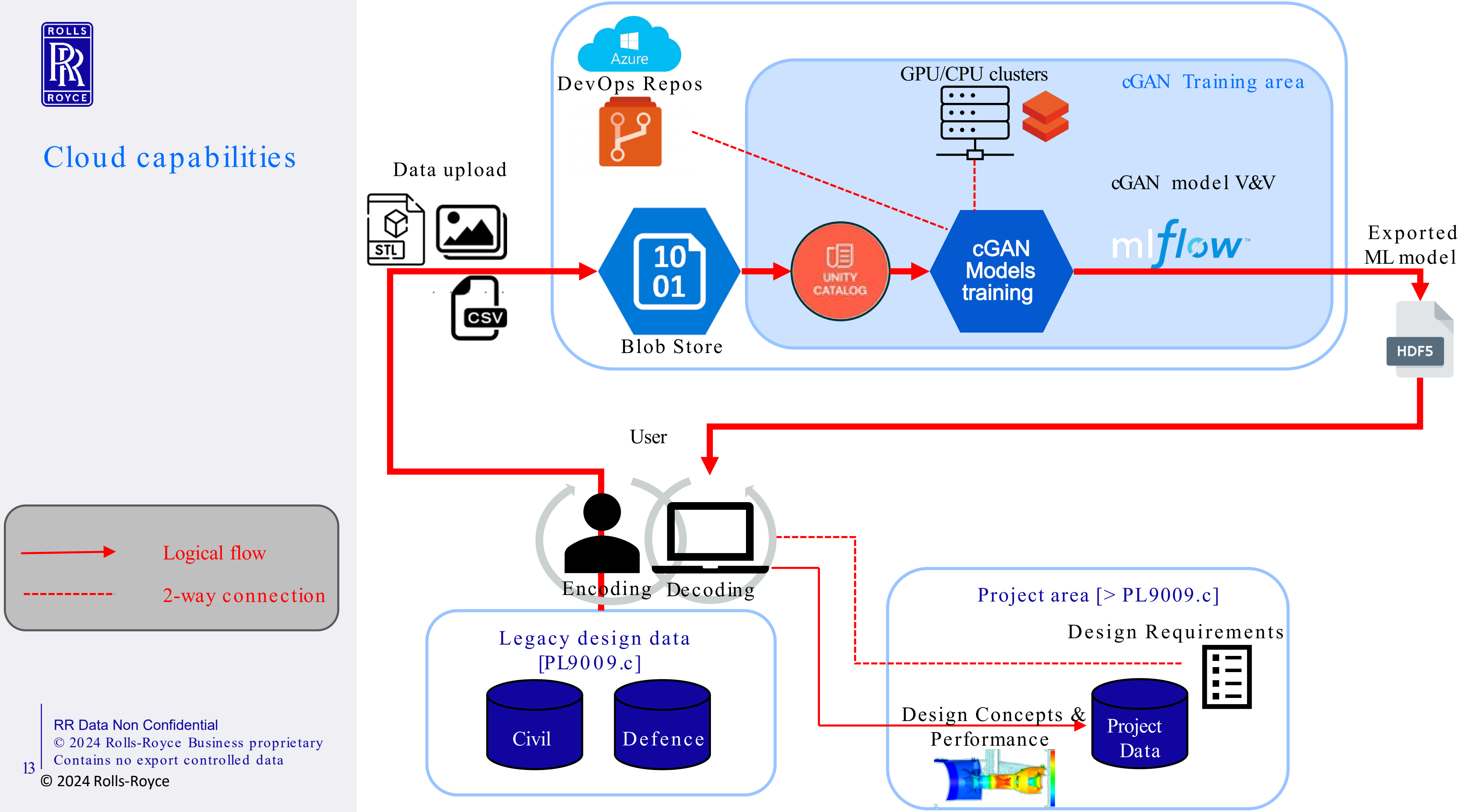






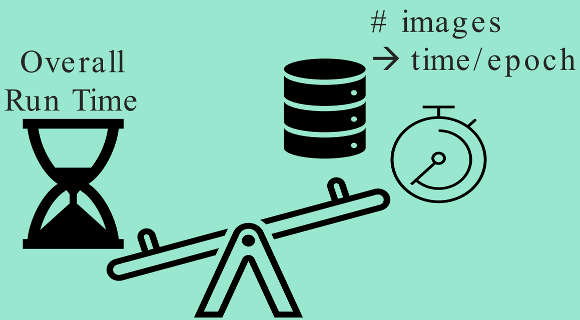
Example of encoded image

Cloud capabilities



Cloud capabilities

Distribution on multi node GPU's



Cloud Advantages

- At least 1 Order of Magnitude reduction in comp time
- Hyperparameters optimisation
- Parallelisation
- Costs
- Scalability
- Traceability (MLFlow)
- Access Control
- Data [pre/post] processing automation

Design of Experiment: CPU vs GPU and Desktop vs Cloud

Exp I	Do ?	Cloud Mlflo Exp ID	Valid on done?	Environm t	Hostname	Cloud Runtime	GPU/C	Sing Node ?	Computat n Spec	package	Package Name reference (Orginal)	File Name	version	architectu	Data	Encoder/ coder	Image Siz	Learning Ra
1	Y		Y	Desktop	GBA-E105039872	N/A	GPU	Y	NVIDIA Quad	Matlab	Matlab		R2021B	NGAN	matlabbeam_98K	Python	128X128	0.0002G/0.
2	Y			Desktop	GBA-E105039870	N/A	GPU	Y	NVIDIA Quad	Pytorch	Pytorch		1.12.1	Conv Layer	matlabbeam_98K	Python	128X128	0.0
3	Y		Y	Desktop	GBA-E105039872	N/A	GPU	Y	NVIDIA Quad	Matlab	Matlab		R2021B	NGAN	matlabbeam_63K	Python	128X128	0.0002G/0.
4	Y			Desktop	GBA-E105039870	N/A	GPU	Y	NVIDIA Quad	Pytorch	Pytorch		1.12.1	Conv Layer	**matlabbeam_63K_matlabe**	Matlab	128X128	0.0
5	Y			Desktop	GBA-E105055523	N/A	CPU	Y	i9-10980XE 3	Pytorch	Pytorch		1.12.1	Conv Layer	matlabbeam_63K	Python	128X128	0.0
6	Y			Desktop	GBA-E105055523	N/A	CPU	Y	i9-10980XE 3	Pytorch	Pytorch		1.12.1	Conv Layer	matlabbeam_63K	Python	128X128	0.0
7	Y	PyTorch_cantile	/	Cloud		14.3 LTS ML	GPU	Y	NC6_sv3, 16G	Pytorch	Pytorch	CGAN with Pytorch	2.0.1+cu118	Conv Layer	matlabbeam_63K	Python	128X128	0.0
8	N		/	Cloud		14.3 LTS ML	GPU	Y	NC6_sv3, 16G	Tensorflow	Tensorflow		2.14.1	Conv Layer	matlabbeam_63K	Python	128X128	0.0
9	N			laptop		N/A	GPU	Y	NVIDIA T120	Pytorch	Pytorch		1.12.1	Conv Layer	matlabbeam_63K	Python	128X129	0.0
10	N			laptop		N/A	CPU	Y	11Gen Intel C	Pytorch	Pytorch		1.10.2	Conv Layer	matlabbeam_63K	Python	128X130	0.0
11	N			laptop		N/A	CPU	Y	11Gen Intel C	Tensorflow	Tensorflow		2.5.0	Conv Layer	matlabbeam_63K	Python	128X131	0.0
12	N		/	Cloud		14.3 LTS ML	GPU	Y	NC6_sv3, 16G	Pytorch	Pytorch		2.0.1+cu118	linear Layer	matlabbeam_63K	Python	128X128	0.0
13	Y	PyTorch_cantile	Y	Cloud		14.3 LTS ML	GPU	Y	NC6_sv3, 16G	Pytorch	Pytorch	CGAN with Pytorch	2.0.1+cu118	Conv Layer	matlabbeam_63K	Python	128X128	0.0
14	Y	PyTorch_cantile	/	Cloud		14.3 LTS ML	GPU	Y	NC6_sv3, 16G	Pytorch	Pytorch	CGAN with Pytorch	2.0.1+cu118	Conv Layer	matlabbeam_63K	Python	128X128	0.0
15	Y			Desktop	GBA-E105055523	N/A	GPU	Y	i9-10980XE 3	Pytorch	Pytorch		1.12.1	Conv Layer	matlabbeam_63K	Python	128X128	0.0
16	N		/	Cloud		14.3 LTS ML	GPU	Y	NC6_sv3, 16G	Pytorch	Pytorch_CKPTS		2.0.1+cu118	Conv Layer	matlabbeam_63K	Python	128X128	0.0
17	N		/	Cloud		14.3 LTS ML	GPU	Y	NC6_sv3, 16G	Pytorch	Pytorch_CKPTS		2.0.1+cu118	Conv Layer	**matlabbeam_63K_matlabe**	Matlab	128X128	0.0
18	Y	PyTorch_cantile	Y	Cloud		14.3 LTS ML	GPU	Y	NC6_sv3, 16G	Pytorch	Pytorch	cgan_pytorch_128x128_v1	2.0.1+cu118	Conv Layer	matlabbeam_63K	Python	128X128	0.0002G/0.
19	Y	PyTorch_cantile	Y	Cloud		14.3 LTS ML	GPU	Y	NC6_sv3, 16G	Pytorch	Pytorch	cgan_pytorch_128x128_v1	2.0.1+cu118	Conv Layer	matlabbeam_63K	Python	128X128	0.0002G/0.
20	Y	PyTorch_cantile	/	Cloud		14.3 LTS ML	GPU	Y	NC6_sv3, 16G	Pytorch	Pytorch	cgan_pytorch_128x128_v1	2.0.1+cu118	Conv Layer	matlabbeam_63K	Python	128X128	0.0002G/0.
21	Y	PyTorch_cantile	/	Cloud		14.3 LTS ML	GPU	Y	NC6_sv3, 16G	Pytorch	Pytorch	cgan_pytorch_128x128_v1	2.0.1+cu118	Conv Layer	matlabbeam_63K	Python	128X128	0.0002G/0.
22	Y	PyTorch_cantile	/	Cloud		14.3 LTS ML	GPU	Y	NC6_sv3, 16G	Pytorch	Pytorch	cgan_pytorch_128x128_v1_ma	2.0.1+cu118	Conv Layer	**matlabbeam_63K_matlabe**	Matlab	128X128	0.0002G/0.
23	Y	PyTorch_cantile	N	Cloud		14.3 LTS ML	GPU	Y	NC6_sv3, 16G	Pytorch	Pytorch_updatedA	cgan_pytorch_128x128_Updat	2.0.1+cu118	Conv Layer	matlabbeam_63K	Python	128X128	0.0002G/0.
24	Y	PyTorch_cantile	/	Cloud		14.3 LTS ML	GPU	Y	NC6_sv3, 16G	Pytorch	Pytorch_updatedA	cgan_pytorch_128x128_Updat	2.0.1+cu118	Conv Layer	matlabbeam_63K	Python	128X128	0.0002G/0.
25	Y	PyTorch64/pers	/	Cloud		14.3 LTS ML	GPU	Y	NC6_sv3, 16G	Pytorch	Pytorch_64x64	cgan_pytorch_64x64 (CGAN wi	2.0.1+cu118	Conv Layer	matlabbeam_63K	Python	64X64	0.0002G/0.

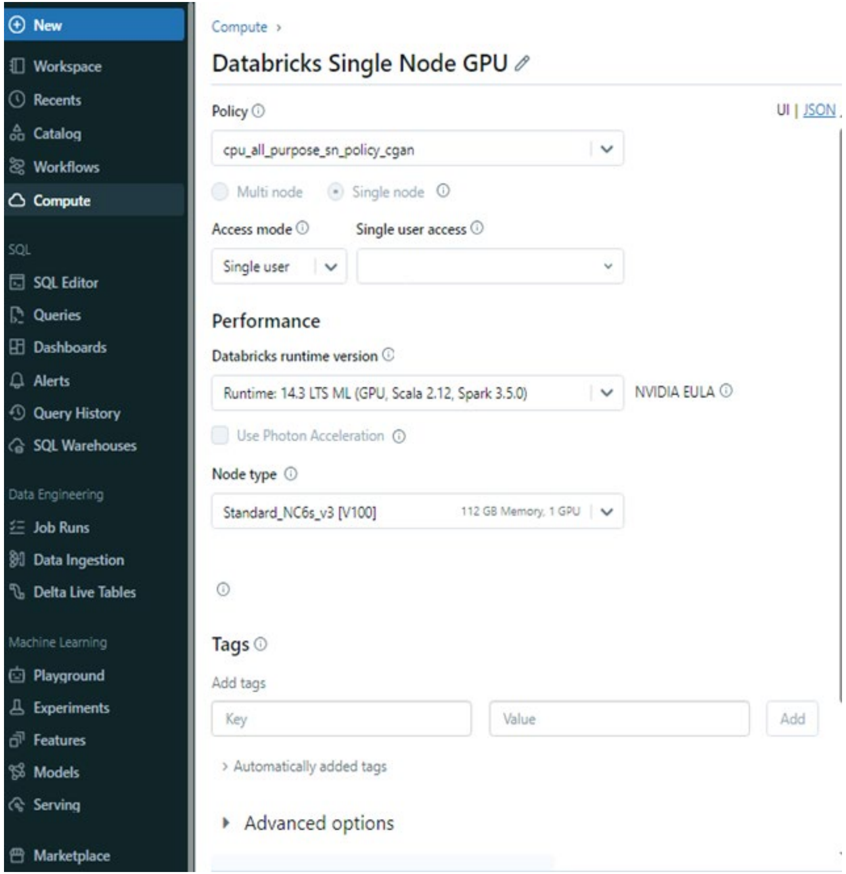
Cloud Compute Strategies

1. Number of images < .5M
   - Single Node GPU

2. Number of images > .5M
   - Single Node multiple GPU parallelization or
   - Multi Node cluster for Distributed computation

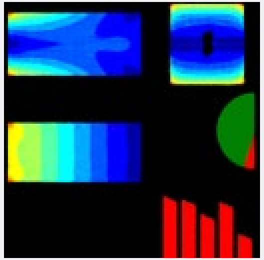
3. Hyperparameter optimisation
   - Multi Node cluster for Distributed computation

Databricks Single GPU config example

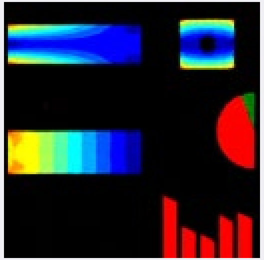


Results:

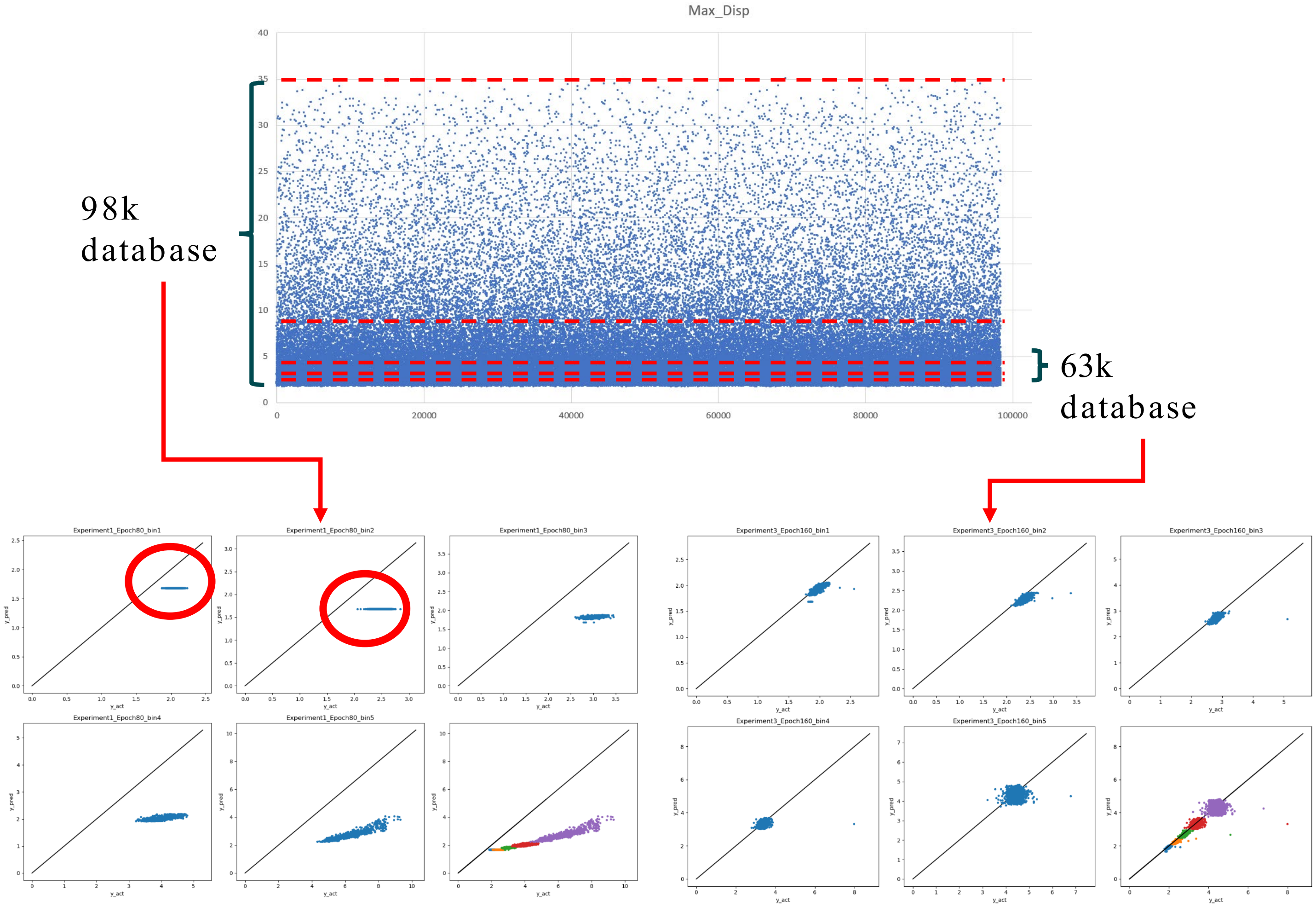
Training data



Bin1 example

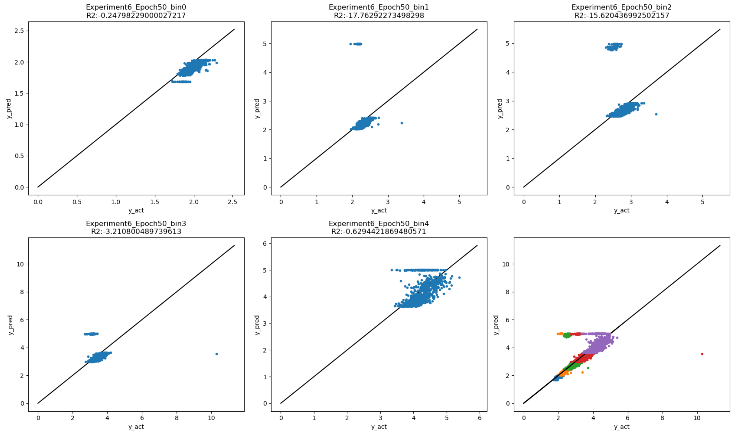


Bin5 example



Results:

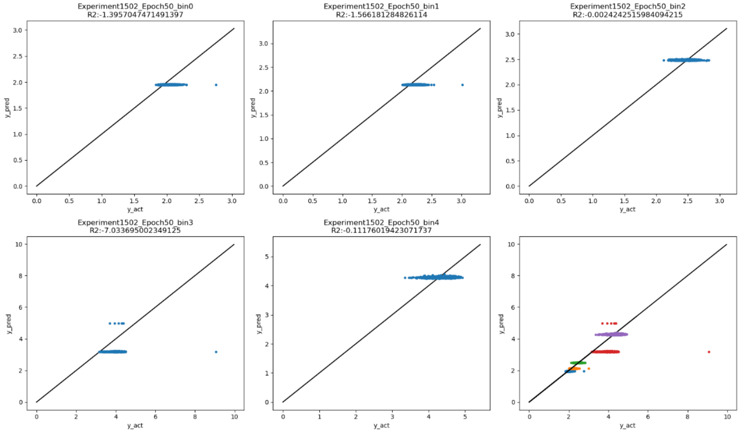
CPU Vs GPU



Exp#6: CPU

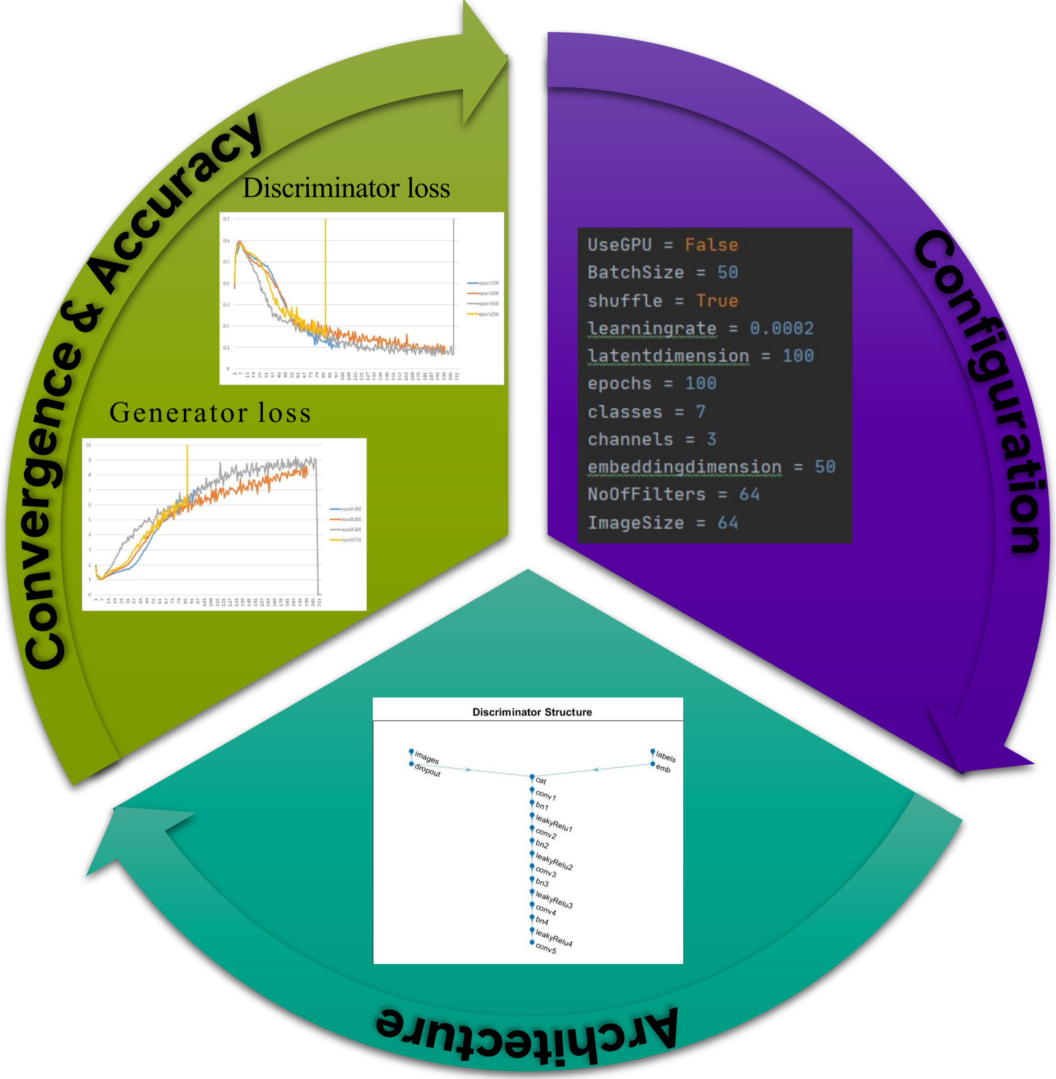
Exp ID	Done ?	Cloud Mlflow Exp ID	Validation don	Environment	Hostname	Cloud Runtime	GPU/CPU	Single Node ?	Computation Spec	package	Package Name reference (Orginal)	File Name	version	architecture	Data	Encoder/Decoder	Image Size	Learning Rate	Batch Size	Number of filte	Number of Latent Dimen
6	Y			Desktop	GBA-E105055523	N/A	CPU	Y	i9-10980XE 3	Pytorch	Pytorch		1.12.1	Conv Layer	matlabbeam_63K	Python	128X128	0.0002	50	64	100
15	Y			Desktop	GBA-E105055523	N/A	GPU	Y	i9-10980XE 3	Pytorch	Pytorch		1.12.1	Conv Layer	matlabbeam_63K	Python	128X128	0.0002	50	64	100

Exp#15: GPU

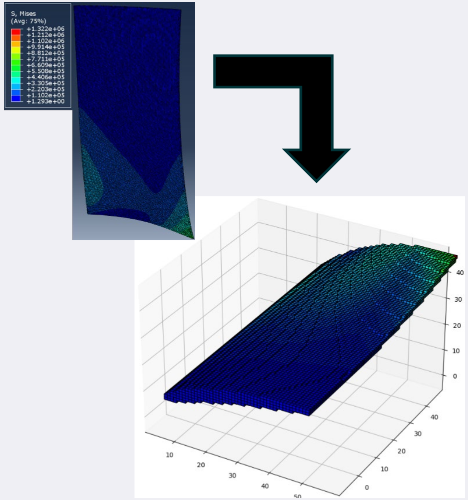


Results:

Current Challenges & WIP

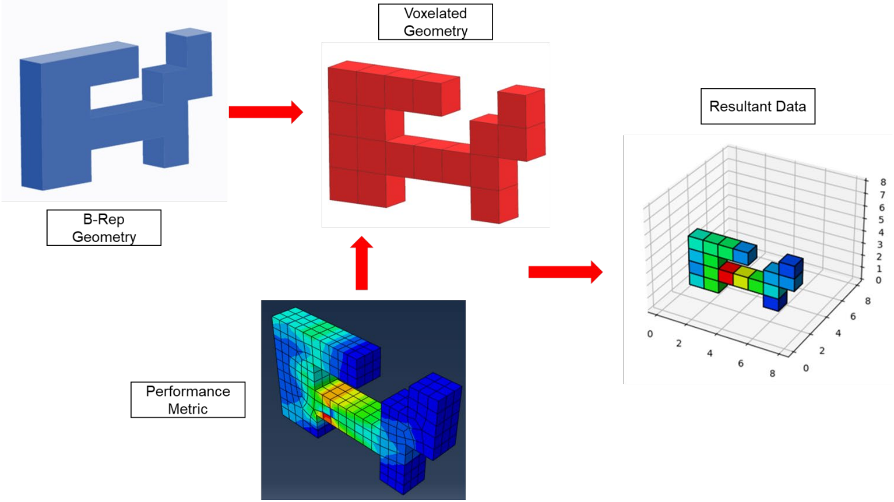


Future work



The IP from ongoing work is protected by patent.

- Short term:
  - Continue investigation and definition of best practices for the setup of settings
  - Dimensionality limits – shift to fully 3D NN processing



- Longer term:
  - How to exploit knowledge from unsuccessful/unconverged simulations
  - How to address studies with multiple (conflicting) objectives and design metrics

NASA Earth At Night, 2017