yDiffusion models – i/p and o/p are of same dimensions- single n/w is used to converge to approximation of a real sample x~ q(x)

DDPM - Denoising Diffusion Probabilistic Model - we get an image from data and add noise step by step. Then We train a model to predict that noise at each step and use the model to generate images

(Sampling Faster) DDIM: Denoising Diffusion Implicit Model

Ref: <https://theaisummer.com/diffusion-models/?fbclid=IwAR1BIeNHqa3NtC8SL0sKXHATHklJYphNH-8IGNoO3xZhSKM_GYcvrrQgB0o>

<https://github.com/diff-usion/Awesome-Diffusion-Models>

architectures that are based on diffusion models are GLIDE, DALLE-2, Imagen, and the full open-source stable diffusion.

<https://insights.daffodilsw.com/blog/all-you-need-to-know-about-diffusion-models>

Applications :

1. Generating image from scratch
2. Conditional image generation – part of image is feeded to model
3. Video generation – high continuity of video frames
4. Text to image generation
5. Anomaly detection – create baseline for normal patterns and then recognize how far points diverge from this normal form
6. Drug discovery – scientists find how molecules move and interact in the body. This computational approach significantly reduces the time and costs associated with bringing new medications to market.
7. Autonomous vehicles -  By predicting the future positions and behaviors of objects in real-time, autonomous vehicles can navigate safely through complex traffic scenarios, adhering to traffic rules and ensuring passenger safety.
8. Neurological research –

* K-space refers to a data matrix containing raw MRI data.
* During MRI acquisition, the scanner collects data point by point, filling up the k-space.
* Each point in k-space represents specific frequency, phase (x, y coordinates), and signal intensity information.
* spatial frequency domain where the entire image is encoded

Dataset:

MRI – time consuming and difficult if we have to run tests through small children (or people with less patience) and large number of people. Too slow for emergency situations like stroke, which doctors need it quickly

FastMRI – AI to make MRI scans. less data is needed using AI and scans can be much faster.

ISMRMD format – Stores MRI data in metadata format – only MRI details like imaging sequence parameters, field strength, slice thickness, echo time (TE), repetition time (TR),

DICOM – Stores both MRI data and Patient information – stores patient details , image params, study details…

Proton density refers to the concentration or density of hydrogen protons within a specific tissue or region being imaged in MRI. Proton density-weighted images provide valuable information about the spatial distribution and concentration of protons within the imaged area.

Tesla – strength of magnetic field generated by MRI scanner

FastMRI: <https://arxiv.org/pdf/1811.08839>

jupyter notebook --notebook-dir=D:/

ssh [idm@idea-hapi.aibe.uni-erlangen.de](mailto:idm@idea-hapi.aibe.uni-erlangen.de)

|  |  |
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| Sethos | ssh [fa51puco@10.203.25.113](mailto:fa51puco@10.203.25.113) |
| Hetep | ssh [fa51puco@10.203.25.114](mailto:fa51puco@10.203.25.114) |
| Harendotes | ssh [fa51puco@10.76.21.13](mailto:fa51puco@10.76.21.13) |
| Hapi | ssh [fa51puco@10.76.21.15](mailto:fa51puco@10.76.21.15) |
| Harmachis | ssh fa51puco@10.76.21.12 |

**:wq**

Location of the data :

For brain:

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|  |  |  |
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| **studyInformation** | Contains information about the study. |  |
| studyTime | The time the study was conducted. | 16:34:16 |
| **measurementInformation** | Includes details about the measurement. |  |
| measurementID | Unique identifier for the measurement. | 35279\_187994673\_187994684\_934 |
| patientPosition | Position of the patient during the scan. | HFS (Head First Supine) |
| protocolName | Name of the imaging protocol. | AX |
| frameOfReferenceUID | Unique identifier for the frame of reference. | 1.3.12.2.1107.5.2.32.35279.1.2 |
| **acquisitionSystemInformation** | Describes the MRI system used for the acquisition. |  |
| systemVendor | Manufacturer of the MRI system. | SIEMENS |
| systemModel | Model of the MRI system. | TrioTim |
| systemFieldStrength\_T | Magnetic field strength in Tesla. | 2.8936 |
| relativeReceiverNoiseBandwidth | Relative bandwidth of the receiver noise. | 0.793 |
| receiverChannels | Number of receiver channels. | 4 |
| institutionName | Name of the institution where the scan was performed. | NYU |
| **experimentalConditions** | Provides details about the experimental conditions. |  |
| H1resonanceFrequency\_Hz | Resonance frequency of hydrogen (H1) in Hz. | 123226984 |
| **encoding** | Contains encoding information for the MRI data. |  |
| **encodedSpace** | Describes the encoded matrix size and field of view. |  |
| matrixSize | Encoded matrix size. | x: 768, y: 392, z: 1 |
| fieldOfView\_mm | Encoded field of view in millimeters. | x: 440, y: 224.62, z: 7.5 |
| **reconSpace** | Describes the reconstruction matrix size and field of view |  |
| matrixSize | Reconstruction matrix size. | x: 384, y: 384, z: 1 |
| fieldOfView\_mm | Reconstruction field of view in millimeters. | x: 220, y: 220, z: 5 |
| **trajectory** | Describes the k-space trajectory used. | cartesian |
| **encodingLimits** | Defines the limits for various encoding steps and parameters. |  |
| kspace\_encoding\_step\_1 | Limits for k-space encoding step 1. | minimum: 0, maximum: 391, |
| kspace\_encoding\_step\_2 | Limits for k-space encoding step 2. | minimum: 0, maximum: 0, |
| average | Limits for averages. | minimum: 0, maximum: 0, center: 0 |
| slice | Limits for slices. | minimum: 0, maximum: 33, center: 0 |
| contrast | Limits for contrast. | minimum: 0, maximum: 0, center: 0 |
| phase | Limits for phase. | minimum: 0, maximum: 0, center: 0 |
| repetition | Limits for repetition. | minimum: 0, maximum: 0, center: 0 |
| set | Limits for set. | minimum: 0, maximum: 0, center: 0 |
| segment | Limits for segment. | minimum: 0, maximum: 0, center: 0 |
| **parallelImaging** | Describes parallel imaging parameters. |  |
| accelerationFactor | Acceleration factor for parallel imaging. | kspace\_encoding\_step\_1: 1, |
| calibrationMode | Calibration mode for parallel imaging. | other |
| **SequenceParameters** | Provides parameters specific to the MRI sequence used. |  |
| TR | Repetition time in milliseconds | 6000 |
| TE | Echo time in milliseconds | 107 |
| TI | Inversion time in milliseconds | 500 |
| flipAngle\_deg | Flip angle in degrees | 120 |
| Sequence\_type | Type of MRI sequence | TurboSpinEcho |
| echo\_spacing | Spacing between echo | 10.72 |
| **userParameters** | Contains user-defined parameters |  |
| **userParameterDouble** | A list of user-defined parameters, here specifically Maxwell coefficients, which are often used in MRI to correct for gradient field imperfections. |  |
| Name |  | MaxwellCoefficient\_0 |
| Value |  | 0 |

Sequence Parameters:

TR: The time between successive pulse sequences applied to the same slice. TR affects the signal intensity and contrast in the resulting images. Short TR times result in T1-weighted images, while long TR times contribute to T2-weighted images.

TE: The time between the application of the RF pulse and the peak of the signal in the receiver coil. TE influences the contrast of the MRI images. Short TE times produce images with T1 contrast, whereas long TE times enhance T2 contrast.

TI: The time between the initial inversion pulse and the start of the signal acquisition. Results in FLAIR (Fluid-Attenuated Inversion Recovery), where it helps in nullifying specific tissue signals to enhance image contrast.

MaxwellCoefficient – using these co-efficients improves the accuracy of the MRI images, as gradient non-linearity leads to spatial distortions.

**Example of Application:**

Imagine an MRI scan where the magnetic field gradients are slightly non-linear. This non-linearity can cause the images to be distorted, making it difficult to accurately measure or diagnose from the images. By using Maxwell coefficients, these distortions can be corrected, ensuring that the resulting images accurately represent the scanned area.

In practice, the actual values for these coefficients would be derived based on the specific characteristics of the MRI scanner and the magnetic field it produces. The coefficients provided in your example are all zero, which might be a placeholder or indicative of a perfectly linear gradient in a theoretical or highly controlled scenario

For Knee:

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<name>MaxwellCoefficient\_14</name>\n\t\t\t

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</userParameterDouble>\n\t\t

<userParameterDouble>\n\t\t\t

<name>MaxwellCoefficient\_15</name>\n\t\t\t

<value>0.000000</value>\n\t\t

</userParameterDouble>\n\t

</userParameters>\n

</ismrmrdHeader>\

|  |  |  |
| --- | --- | --- |
| Element | Description | Example |
| **ismrmrdHeader** | Root element indicating the content follows the ISMRMRD format |  |
| **studyInformation** | Contains information about the study. |  |
| studyTime | The time the study was conducted. | 13:56:13 |
| **measurementInformation** | Includes details about the measurement. |  |
| measurementID | Unique identifier for the measurement. | 51022\_80205133\_80205142\_342 |
| patientPosition | Position of the patient during the scan. | FFS |
| protocolName | Name of the imaging protocol. | COR |
| frameOfReferenceUID | Unique identifier for the frame of reference. | 1.3.12.2.1107.5.2.38.51022.1.20180408134532241.0.0.5022 |
| **acquisitionSystemInformation** | Includes details about the acquisition system. |  |
| systemVendor | Vendor of the system. | SIEMENS |
| systemModel | Model of the system. | Biograph\_mMR |
| systemFieldStrength\_T | Magnetic field strength in Tesla. | 2.893620 |
| relativeReceiverNoiseBandwidth | Relative receiver noise bandwidth. | 0.793000 |
| receiverChannels | Number of receiver channels. | 15 |
| **coilLabel** | Information about the coils used. |  |
| coilNumber | Coil number. | 9, 21, 15, 7, 23, 19, 31, 3, 25, 29, 5, 27, 11, 13, 17 |
| coilName | Coil name. | TxRx\_15Ch\_Knee:1:K15, TxRx\_15Ch\_Knee:1:K9, etc. |
| institutionName | Name of the institution. | NYU |
| **experimentalConditions** | Includes details about experimental conditions. |  |
| H1resonanceFrequency\_Hz | H1 resonance frequency in Hertz. | 123215683 |
| **encoding** | Includes details about the encoding parameters. |  |
| **encodedSpace** | Space that is encoded. |  |
| matrixSize | Size of the matrix. | x: 640, y: 356, z: 1 |
| fieldOfView\_mm | Field of view in millimeters. | x: 280.000000, y: 155.539993, z: 4.500000 |
| **reconSpace** | Space for reconstruction. |  |
| matrixSize | Size of the matrix. | x: 320, y: 320, z: 1 |
| fieldOfView\_mm | Field of view in millimeters. | x: 140.000000, y: 140.000000, z: 3.000000 |
| **encodingLimits** | Limits for encoding. |  |
| kspace\_encoding\_step\_1 | Encoding step 1 in k-space. | minimum: 0, maximum: 319, center: 160 |
| kspace\_encoding\_step\_2 | Encoding step 2 in k-space. | minimum: 0, maximum: 0, center: 0 |
| average | Average encoding limits. | minimum: 0, maximum: 0, center: 0 |
| slice | Slice encoding limits. | minimum: 0, maximum: 35, center: 0 |
| contrast | Contrast encoding limits. | minimum: 0, maximum: 0, center: 0 |
| phase | Phase encoding limits. | minimum: 0, maximum: 0, center: 0 |
| repetition | Repetition encoding limits. | minimum: 0, maximum: 0, center: 0 |
| set | Set encoding limits. | minimum: 0, maximum: 0, center: 0 |
| segment | Segment encoding limits. | minimum: 0, maximum: 0, center: 0 |
| trajectory | Type of trajectory used. | cartesian |
| **parallelImaging** | Details about parallel imaging. |  |
| accelerationFactor | Acceleration factors for k-space encoding steps. | kspace\_encoding\_step\_1: 1, kspace\_encoding\_step\_2: 1 |
| calibrationMode | Calibration mode for parallel imaging. | other |
| **sequenceParameters** | Details about the sequence parameters. |  |
| TR | Repetition time in milliseconds. | 2600.000000 |
| TE | Echo time in milliseconds. | 27.000000 |
| TI | Inversion time in milliseconds. | 100.000000 |
| flipAngle\_deg | Flip angle in degrees. | 140.000000 |
| sequence\_type | Type of sequence used. | TurboSpinEcho |
| echo\_spacing | Echo spacing in milliseconds. | 8.850000 |
| **userParameters** | Includes user-defined parameters. |  |
| userParameterDouble | User-defined parameters with double precision values. |  |
| name | Name of the user parameter. | MaxwellCoefficient\_0, MaxwellCoefficient\_1, etc. |
| value | Value of the user parameter. | 0.000000 |

**Denoising diffusion models for denoising diffusion MRIs:**

GANs – inspired from human cognition system – superior AI for content generation – not perfect – not able to find distinction between generator and discriminator and if one is not trained well , other one will not be able to converge – to overcome all these diffusion models have been proposed – inspired from physics – dealing with probabilities and model the probabilities through Markov chain with multipl states. Each of states in chain represents a distribution which is posterior w.r.t previous state or prior dist. W.r.t. following state – can be used to learn mapping between prior to posterior – diffusion doesn’t need discrimination at all but instead iteration of generation process at each states until the final result

Iterating through the states we are recovering from the noise. Diffusion models not only denoise the samples but also push the samples to correct cluster and that’s how it fits any data distribution.

7 min to generate one single scan -> we can acquire noisy image in shorter time and train neural networks to generate their clean correspondences through denoising NN. This is whole efficient than the original 7 min.

MRI – W, H, D, T (Widh, height, depth and number of different representations) 3D

Approach 1) unconditional diffusion model DDPM – start with noise Z and recurd every state in Markov chain to get fine clean image .

2) if the inbetween states is noisy after recurrent states, replace one of the states with input and start training from there – conditions generation,

J invariance – assume noise is independently sampled form the same dist. And different noisy observations actually represent the same underlying pattern. So we can train NN with different noise observations so no clean branches is required at this case.

DDM2 – 3 states – stage 1 – learn noise model through j invariance – ok denoising quality – over smoothed result and lack essential details . simple method so we need next 2 stages

Stage 2 – merge a noisy input to a particular intermediate state in Markov chain. Use residual noise from stage 1 and fit a noise dist..each intermediate state has different noise levels , so find a close match between fitted noise dist. And this intermediate dist. - A successful match tells there exists atleast one possible sample from posterior at this state in unconditional Markov chain . A denoised image can be generated by starting generation at the matched state instead.

Stage 3 – Diffusion model training

DDPM , score based diffusion

<https://www.youtube.com/watch?v=H45lF4sUgiE>

<https://www.youtube.com/watch?v=a4Yfz2FxXiY>

DDPM

Forward process:

Idea of diffusion models is to destroy all info in the image progressively in sequence of time – add little bit of guassian noise at each step and get completely random noise at the end by mimicking the i/p,.

Reverse – from xt to x0 in reverse process via NN model – take image and remove noise step b by step.

Once the step is learned , take random noise sampled from normal distribution and it will remove little bit of noise – denoising

Diffusion : complex distribution to a simple distribution

<https://www.assemblyai.com/blog/diffusion-models-for-machine-learning-introduction/>

Cramify

Bayes by back prop: Instead of fixed weights, we use weight that can change and have uncertainty. The network learns by adjusting the uncertain weights to better fit the data. Use VI to update guesses.

Back prop – adjust both guesses and uncertainty. Adv: not only tells us the predictions but also tells us how confident the prediction is, avoid overfitting

* VarNet improves this by learning to predict sensitivity maps from available data.

VarNet: This is a specific deep learning method for MRI reconstruction. It uses several layers, each designed to improve the MRI image in a step-by-step manner.

Gradient Update: Each layer of VarNet mimics a gradient update step, which is a mathematical way to iteratively improve an image.

Score based diffusion models: data is gradually transformed into noise and then gradually reverse the process to generate new samples.

**Why is Score Matching Useful?**

* **Handling Complex Distributions**: Estimating the score function can be easier and more stable than directly estimating the probability density function, especially for high-dimensional or complex data distributions.
* **Langevin Dynamics**: Once the score function is learned, it can be used to generate new samples. Langevin dynamics is a method that uses the score function to iteratively adjust random noise until it follows the learned data distribution.

Initisl issue – directly applying score matching might cause struggle in areas where data is sparse – leading to poor score estimates and bad data generation.

So add noise – leads to variation in training data dn helps the model to learn more accurate scores in low density regions

Advanced method – instead of adding noise directly , data is perturbed (add noise while confedentialy is maintained) using SDE. Generative process is recovered by reversing this diffusion using score matching techniques combined with annealed Langevin dynamics

**Mask Functions in fastmri**

Center Fractions: This parameter controls how much of the central region of k-space is always included in the mask. The central region of k-space contains the low-frequency components, which are critical for image contrast and overall quality.

Acceleration Factors: This determines how much the data acquisition is accelerated. For example, an acceleration factor of 4 means that only 1 out of 4 lines of k-space is sampled. The rest are undersampled, which reduces scan time but introduces artifacts that need to be addressed during reconstruction

**RandomMaskFunc**:

Description: This function creates a mask that randomly selects lines in k-space. The selection is based on specified center fractions and acceleration factors.

**EquiSpacedMaskFunc**:

Description: This function creates a mask that selects lines in k-space at regular intervals. The selection is based on specified center fractions and acceleration factors.

**EquispacedMaskFractionFunc:**

Description: Similar to EquiSpacedMaskFunc, but it allows for more control over the fraction of k-space lines that are selected.

**MagicMaskFunc:**

Description: This function creates a mask using a more complex algorithm that aims to optimize the sampling pattern for better image reconstruction.

**Complex Algorithm**: The "magic" in the name suggests that this mask function employs a more advanced strategy than simple random or equispaced sampling. It might use techniques like optimization or adaptive sampling to better balance image quality and acquisition time.

**MagicMaskFractionFunc:**

Description: Similar to MagicMaskFunc, but it allows for more control over the fraction of k-space lines that are selected.

A close-up of a baby's head

Description automatically generated

!wget -O models/ldm/stable-diffusion-v1/model.ckpt https://huggingface.co/CompVis/stable-diffusion-v-1-4-original/resolve/main/sd-v1-4.ckpt

**Meta data count results**

**Knee data**

**Training Data:**

|  |  |  |  |
| --- | --- | --- | --- |
| Acquisition | Magnetic Field | System Model | File Count |
| CORPDFS\_FBK | 1.494 | Aera | 206 |
| CORPDFS\_FBK | 2.89362 | Biograph\_mMR | 54 |
| CORPDFS\_FBK | 2.89362 | Prisma\_fit | 19 |
| CORPDFS\_FBK | 2.89362 | Skyra | 210 |
| CORPD\_FBK | 1.494 | Aera | 205 |
| CORPD\_FBK | 2.89362 | Biograph\_mMR | 50 |
| CORPD\_FBK | 2.89362 | Prisma\_fit | 22 |
| CORPD\_FBK | 2.89362 | Skyra | 207 |

**Validation Data:**

|  |  |  |  |
| --- | --- | --- | --- |
| Acquisition | Magnetic Field | System Model | File Count |
| CORPDFS\_FBK | 1.494 | Aera | 47 |
| CORPDFS\_FBK | 2.89362 | Biograph\_mMR | 10 |
| CORPDFS\_FBK | 2.89362 | Prisma\_fit | 3 |
| CORPDFS\_FBK | 2.89362 | Skyra | 39 |
| CORPD\_FBK | 1.494 | Aera | 47 |
| CORPD\_FBK | 2.89362 | Biograph\_mMR | 10 |
| CORPD\_FBK | 2.89362 | Prisma\_fit | 3 |
| CORPD\_FBK | 2.89362 | Skyra | 40 |

|  |  |
| --- | --- |
| File names for reference (Training data): |  |
| File names for reference (Validation data): |  |

**Brain Data**

**Training Data:**

|  |  |  |  |
| --- | --- | --- | --- |
| **Acquisition** | **Magnetic Field** | **System Model** | **File Count** |
| AXFLAIR | 1.494 | Aera | 79 |
| AXFLAIR | 2.8936 | Biograph\_mMR | 23 |
| AXFLAIR | 2.8936 | Prisma\_fit | 47 |
| AXFLAIR | 2.8936 | Skyra | 138 |
| AXFLAIR | 2.8936 | TrioTim | 57 |
| AXT1 | 1.494 | Aera | 204 |
| AXT1 | 2.8936 | Skyra | 44 |
| AXT1POST | 1.494 | Aera | 181 |
| AXT1POST | 1.494 | Avanto | 375 |
| AXT1POST | 2.8936 | Biograph\_mMR | 65 |
| AXT1POST | 2.8936 | Prisma\_fit | 52 |
| AXT1POST | 2.8936 | Skyra | 186 |
| AXT1POST | 2.8936 | TrioTim | 90 |
| AXT1PRE | 1.494 | Aera | 25 |
| AXT1PRE | 2.8936 | Biograph\_mMR | 39 |
| AXT1PRE | 2.8936 | Prisma\_fit | 31 |
| AXT1PRE | 2.8936 | Skyra | 69 |
| AXT1PRE | 2.8936 | TrioTim | 86 |
| AXT2 | 1.494 | Aera | 443 |
| AXT2 | 1.494 | Avanto | 587 |
| AXT2 | 2.8936 | Biograph\_mMR | 369 |
| AXT2 | 2.8936 | Prisma\_fit | 349 |
| AXT2 | 2.8936 | Skyra | 824 |
| AXT2 | 2.8936 | TrioTim | 106 |

**Validation Data:**

|  |  |  |  |
| --- | --- | --- | --- |
| **Acquisition** | **Magnetic Field** | **System Model** | **File Count** |
| AXFLAIR | 1.494 | Aera | 28 |
| AXFLAIR | 2.8936 | Biograph\_mMR | 7 |
| AXFLAIR | 2.8936 | Prisma\_fit | 12 |
| AXFLAIR | 2.8936 | Skyra | 47 |
| AXFLAIR | 2.8936 | TrioTim | 13 |
| AXT1 | 1.494 | Aera | 82 |
| AXT1 | 2.8936 | Skyra | 10 |
| AXT1POST | 1.494 | Aera | 46 |
| AXT1POST | 1.494 | Avanto | 98 |
| AXT1POST | 2.8936 | Biograph\_mMR | 21 |
| AXT1POST | 2.8936 | Prisma\_fit | 19 |
| AXT1POST | 2.8936 | Skyra | 60 |
| AXT1POST | 2.8936 | TrioTim | 43 |
| AXT1PRE | 1.494 | Aera | 7 |
| AXT1PRE | 2.8936 | Biograph\_mMR | 12 |
| AXT1PRE | 2.8936 | Prisma\_fit | 7 |
| AXT1PRE | 2.8936 | Skyra | 20 |
| AXT1PRE | 2.8936 | TrioTim | 31 |
| AXT2 | 1.494 | Aera | 128 |
| AXT2 | 1.494 | Avanto | 214 |
| AXT2 | 2.8936 | Biograph\_mMR | 109 |
| AXT2 | 2.8936 | Prisma\_fit | 85 |
| AXT2 | 2.8936 | Skyra | 227 |
| AXT2 | 2.8936 | TrioTim | 52 |

|  |  |
| --- | --- |
| File names for reference (Training data): |  |
| File names for reference (Validation data): |  |