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DISCENSYS

Openminds Technologies

Machine Learning Course

Introduction to Machine Learning
Python, ML Tools & Git Workflow
Data Preprocessing
Exploratory Data Analysis (EDA) & Visualization
Feature Engineering
Feature Selection & Dimensionality Reduction
Supervised Learning — Regression
Supervised Learning — Classification
Unsupervised Learning — Clustering
Anomaly Detection
Time Series Analysis & Forecasting
Model Optimization & Explainability
Classical ML Algorithms & Advanced Ensembles
NLP Fundamentals with Machine Learning
Model Deployment & MLOps Essentials



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Generative AI Course Syllabus

Comprehensive · Practical · Industry-Ready

45

Total Sessions

40

Teaching Sessions

9

Weeks

5

Sessions / Week

Mon-Fri

Schedule

Course Overview

Program Structure

This course runs across 9 weeks (45 sessions, Mon-Fri). Weeks 1-8 are 40 dedicated teaching sessions covering 13 modules -- from generative model foundations through VAEs, GANs, Diffusion Models, Transformers, LLMs, Prompt Engineering, Multimodal AI, Fine-Tuning, RAG, and Production Deployment. Week 9 (sessions 41-45) is the Capstone & Career Week -- project development, a Resume & Career Readiness Workshop, final presentations, and course wrap-up.

Prerequisite: Machine Learning fundamentals are required -- Python, NumPy, pandas, sklearn, and core ML concepts (supervised learning, cross-validation, model evaluation). Completion of the Open Minds Technologies ML course is strongly recommended.

Assignment Submission -- Centralised GitHub Organisation Repo

All assignments -- daily, weekly, bi-weekly, and the capstone -- are submitted as pull requests to the centralised course organisation repository on GitHub. Each learner works on their own named branch, pushes their work, and opens a PR for instructor review. This mirrors exactly how professional AI engineering teams collaborate on shared codebases.

Daily assignments are pushed to the learner's branch and a PR is opened by end of each session. Weekly assignments are submitted as a PR at the end of each week, reviewed by the instructor before the next week begins. Bi-weekly team assignments are raised from a shared team branch. The capstone project lives in its own dedicated repo under the organisation. This single centralised workflow gives instructors full visibility of every learner's progress in one place -- and gives learners a real-world PR review experience from day one.

Daily Assignments (Individual)

Every session has a daily assignment -- short, targeted coding tasks that reinforce the exact concept taught that day. Pushed to the learner's branch on the org repo and a PR opened by end of day. These are the primary vehicle for developing hands-on proficiency.

Weekly Assignments (Individual)

At the end of each teaching week, learners raise a PR on the org repo covering all topics from that week. The instructor reviews, leaves inline comments, and either requests changes or merges -- giving learners structured, code-level feedback on their understanding.

Bi-Weekly Assignments (Team)

Every two weeks, teams push their collaborative solution to a shared team branch on the org repo and raise a PR. The team manages the branch together -- dividing work, reviewing each other's commits, and resolving conflicts before the PR is submitted. Mirrors real team delivery.

Capstone Project (Team) -- Week 9 (Sessions 41-45)

Teams build an end-to-end Generative AI application -- from model selection and fine-tuning through to a deployed, production-ready API. The project lives in a dedicated repo under the organisation. Mentor reviews happen via PR comments. Certificate of completion issued upon successful delivery and final presentation.

Assessment Type	Frequency	Submission Method	Mode
Daily Assignment	Every session	Push to learner branch + PR on org repo	Individual

Weekly Assignment	End of each teaching week	PR on org repo -- instructor reviewed	Individual
Bi-Weekly Assignment	Every 2 weeks	Team branch PR on org repo	Team
Capstone Project	Week 9 (Sessions 41-45)	Dedicated org repo + Final Presentation	Team

Weekly Module Breakdown

Week 1 | Sessions 1-5

Foundations of Generative AI & Neural Network Basics

Mon	Tue	Wed	Thu	Fri
S1	S2	S3	S4	S5
Gen AI introduction -- generative vs discriminative, applications & landscape	Probability distributions, latent variables & model evaluation metrics	Neural networks review -- feedforward nets, activations, backprop & PyTorch	Autoencoders -- encoder-decoder architecture, reconstruction loss & hands-on	Latent space representation -- interpolation, visualisation & limitations

Module 1: Foundations of Generative AI

Sessions 1-2

• What is Generative AI:

Learning the data distribution $P(X)$ to generate new, realistic samples
 Generative vs Discriminative -- $P(X)$ vs $P(Y|X)$; fundamentally different learning objectives
 Key applications -- image synthesis, text generation, audio creation, drug discovery, code generation
 The generative AI landscape -- VAEs, GANs, Diffusion Models, Transformers, LLMs; when to use each

• Probability foundations:

Probability distributions -- Gaussian, Bernoulli, Categorical; how data distributions are modelled
 Sampling -- ancestral sampling, rejection sampling; drawing new examples from a learned distribution
 KL divergence -- measuring distance between two distributions; central to VAE training and RLHF
 Monte Carlo estimation -- approximating intractable integrals via random sampling

• Latent variable models:

Observed variables X vs latent (hidden) variables Z -- the generative story
 Generative process: sample Z from prior $P(Z)$, then generate X from $P(X|Z)$
 Marginal likelihood $P(X)$ requires integrating over all Z -- why exact inference is intractable
 Posterior inference $P(Z|X)$ -- the core learning challenge; approximation methods are necessary

• Evaluation of generative models:

Likelihood -- valid when tractable; cannot be computed for GANs and Diffusion Models
 Frechet Inception Distance (FID) -- joint quality and diversity measure for image generation
 Inception Score (IS) -- sharpness + variety; ignores the real data distribution
 BLEU, ROUGE, BERTScore -- text evaluation; each captures different quality dimensions
 Human evaluation -- gold standard for creative and open-ended generation tasks
 No single metric is sufficient -- always use multiple complementary measures

Module 2: Neural Network Basics for Generation

Sessions 3-5

Prerequisite: ML fundamentals assumed -- Python, NumPy, pandas, sklearn

• Feedforward networks review:

Layers, weights, biases -- the computation graph; parameters learned via gradient descent
 Activation functions -- ReLU, GELU, Sigmoid, Tanh; introducing non-linearity into the network
 Forward pass -- input to hidden layers to output; matrix multiplications + activations
 Backpropagation -- chain rule; computing gradients with respect to every parameter layer-by-layer

Vanishing and exploding gradients -- batch normalisation, skip connections, gradient clipping as remedies

- **PyTorch for deep learning:**

Tensors -- creation, shapes, dtype, device management (CPU/GPU); GPU acceleration with .cuda()
nn.Module -- defining models; forward() method; composing layers with nn.Sequential
Optimizers -- Adam, AdamW; learning rate scheduling (cosine decay, warmup steps)
Training loop -- zero_grad, forward pass, loss computation, backward, optimizer step
DataLoader -- batching, shuffling, num_workers; custom Dataset class for any data format

- **Autoencoders:**

Encoder -- compresses input X to a bottleneck latent vector Z via learned mappings
Decoder -- reconstructs $\hat{X}$ from Z; learning the inverse Z to X mapping
Reconstruction loss -- MSE for continuous data; BCE for binary or pixel data
Bottleneck dimension -- controls compression vs information retention tradeoff
Denoising autoencoders -- adds noise to input; forces robust, generalizable feature learning
Limitations -- irregular latent space; cannot reliably sample novel data from Z

- **Latent space representation:**

What the latent space captures -- semantic structure; similar inputs cluster nearby in Z
Interpolation -- linear path between two Z points produces smooth semantic transitions
t-SNE and UMAP -- 2D visualisation of high-dimensional latent spaces
Disentanglement -- individual Z dimensions correspond to interpretable data factors
Why plain autoencoders fail for generation -- no prior on Z; gaps in latent space produce garbage

- **Git & GitHub -- centralised org repo workflow from day one:**

git clone -- clone the course organisation repo to your local machine
git checkout -b firstname-lastname/daily/session-01 -- your personal branch naming convention
git add, git commit, git push -- the daily assignment submission cycle
Pull Requests -- open a PR from your branch to main after every assignment; instructor reviews inline
.gitignore -- excluding venvs, __pycache__, .ipynb_checkpoints, model weights, .env files

Week 2 | Sessions 6-10

Variational Autoencoders & GANs -- Part 1

Mon	Tue	Wed	Thu	Fri
S6	S7	S8	S9	S10
VAE I -- probabilistic interpretation & reparameterization trick	VAE II -- KL divergence & ELBO objective	VAE III -- PyTorch implementation, variants & limitations	GAN I -- generator & discriminator, minimax game formulation	GAN II -- training instability, mode collapse & DCGAN architecture

Module 3: Variational Autoencoders (VAE)

Sessions 6-8

- **Probabilistic interpretation:**

Encoder as approximate posterior $q(Z|X; \phi)$ -- outputs mean (μ) and std (σ) of Z
Decoder as likelihood $P(X|Z; \theta)$ -- generates reconstruction from a sampled Z
Goal -- learn parameters θ and ϕ to maximise data log-likelihood $\log P(X)$
Intractability -- marginal $P(X) = \int P(X|Z)P(Z) dZ$ requires approximation

- **Reparameterization trick:**

Direct sampling $Z \sim N(\mu, \sigma^2)$ is non-differentiable -- gradients cannot flow back through it
Rewrite as $Z = \mu + \sigma * \epsilon$, $\epsilon \sim N(0,1)$ -- stochasticity shifted to ϵ ; μ and σ stay differentiable
Enables end-to-end backpropagation through the sampling operation -- critical for training VAEs

- **KL Divergence:**

Measures divergence between approximate posterior $q(Z|X)$ and standard prior $P(Z) = N(0,1)$
KL term regularises latent space -- pulls the posterior toward a compact, smooth Gaussian prior
Closed-form for Gaussians: $KL = -0.5 * \sum (1 + \log \sigma^2 - \mu^2 - \sigma^2)$
KL annealing -- gradually increase KL weight during training; prevents posterior collapse early on
Posterior collapse -- decoder ignores Z entirely; occurs when KL weight overpowers reconstruction

- **ELBO Objective:**

$$\text{ELBO} = \mathbb{E}[\log P(X|Z)] - \text{KL}(q(Z|X) \parallel P(Z))$$

Reconstruction term -- how faithfully X is reconstructed from a sampled Z

Regularisation term -- how close the learned posterior is to the prior

Maximising ELBO = maximising a lower bound on $\log P(X)$; tightens as the posterior improves

Beta-VAE -- ELBO with $\beta > 1$ on KL; stronger disentanglement at cost of reconstruction quality

• VAE variants & limitations:

Conditional VAE (CVAE) -- condition encoder & decoder on class label; enables controlled generation

VQ-VAE -- discrete latent codes via vector quantisation; used in DALL-E 1 and AudioLM

Blurry outputs -- MSE reconstruction loss averages over modes; misses sharp high-frequency detail

VAEs vs GANs vs Diffusion -- VAEs: stable training, interpretable Z, blurry outputs; Diffusion: highest quality

Module 4: Generative Adversarial Networks (GANs)

Sessions 9-11

• Generator and Discriminator:

Two-network adversarial game -- G and D trained simultaneously against each other

G: noise Z maps to synthetic sample X_{fake} ; aims to fool D into classifying fakes as real

D: binary classifier -- real (1) vs generated (0); trained to tell them apart

Alternating training -- D updated k steps per G update; maintaining balance is key

• Minimax Game:

Objective: $\min_G \max_D \mathbb{E}[\log D(X_{\text{real}})] + \mathbb{E}[\log(1 - D(G(Z)))]$

D maximises -- correctly classifying real as real and fake as fake

G minimises -- making D classify $G(Z)$ as real; non-saturating loss used in practice

Nash equilibrium -- optimal G produces a distribution indistinguishable from real data

Why difficult -- saddle point optimisation; no convergence guarantee in practice

• Training Instability & DCGAN:

Mode collapse -- G produces limited variety; ignores large parts of the real data distribution

Vanishing gradients for G -- when D is too strong; G receives near-zero gradient signal

Practical fixes -- label smoothing (0.9 not 1.0), instance noise, spectral normalisation

DCGAN -- convolutional G (transposed convolutions) and D (strided convolutions); no FC hidden layers

DCGAN rules -- batch normalisation in both G and D; LeakyReLU in D; ReLU in G; Tanh output

Week 3 | Sessions 11-15

GANs -- Completion & Diffusion Models

Mon	Tue	Wed	Thu	Fri
S11	S12	S13	S14	S15
GAN III -- WGAN, StyleGAN & conditional GANs	Diffusion I -- forward process, noise scheduling & Markov chain	Diffusion II -- DDPM, score-based models & reverse process	Diffusion III -- Stable Diffusion, CLIP conditioning & CFG	Diffusion IV -- DDIM sampling, implementation walkthrough & hands-on

Module 4: GANs -- continued

Session 11

• WGAN (Wasserstein GAN):

Wasserstein-1 distance -- more meaningful metric when real and fake supports do not overlap

Critic -- unbounded real-valued score replaces the sigmoid discriminator

Lipschitz constraint -- weight clipping (original) or gradient penalty (WGAN-GP); stabilises training

More stable training -- meaningful gradient for G even when distributions are far apart

• StyleGAN:

Mapping network -- 8-layer MLP maps noise Z to intermediate latent W; disentangles style factors

AdaIN (Adaptive Instance Normalisation) -- injects W at each conv layer to control style at that scale

Stochastic variation -- per-pixel Gaussian noise at each layer for fine texture details

Style controls scale -- coarse layers control shape and pose; fine layers control texture and colour

• Conditional GAN (cGAN):

Condition G and D on class label, attribute embedding, or reference image

Applications -- class-conditional image generation, image-to-image translation (Pix2Pix, CycleGAN)
 Why GANs matter historically -- understanding adversarial training underpins modern alignment concepts
 GANs in 2025+ -- largely superseded by Diffusion for images; still used in video, audio, domain adaptation

Module 5: Diffusion Models

Sessions 12-15

• Forward Diffusion Process:

Gradually adds Gaussian noise over T timesteps -- a fixed Markov chain on data X
 $q(X_t | X_{t-1}) = N(X_t; \sqrt{1-\beta_t} * X_{t-1}, \beta_t * I)$ -- each step adds small noise
 Noise schedule -- linear (original DDPM) or cosine; controls how fast the signal is destroyed
 Closed-form: $X_t = \sqrt{\alpha_t} * X_0 + \sqrt{1-\alpha_t} * \epsilon$ -- jump to any timestep
 By step $T = 1000$, X_T approximates $N(0, I)$ -- X_0 is fully destroyed into pure Gaussian noise

• Reverse Diffusion Process:

Learn to denoise -- neural network predicts X_{t-1} given noisy X_t and timestep t
 Parameterize as noise prediction $\epsilon_\theta(X_t, t)$ -- more stable than predicting X_0 directly
 At inference: start from pure Gaussian noise X_T ; iteratively apply learned denoising T times
 U-Net backbone -- skip connections preserve spatial detail; timestep embedding injected at each block

• DDPM (Denoising Diffusion Probabilistic Models):

Training -- uniformly sample t ; add noise to X_0 ; train network to predict the added noise ϵ
 Loss -- MSE between predicted noise and actual noise; simple and very stable to optimise
 Sampling -- 1000 denoising steps; high quality but slow at inference time
 DDIM (Denoising Diffusion Implicit Models) -- deterministic sampling; 50-100 steps without quality loss

• Score-based Models:

Score function $\text{grad}_x \log P(x)$ -- gradient of log-density; points toward higher-probability regions
 Score matching -- train a neural net to estimate the score function directly from data
 Langevin dynamics -- iterative refinement using estimated score + injected noise
 SDE perspective -- forward and reverse diffusion as continuous stochastic differential equations
 Equivalence -- score-based models and DDPM are two views of the same underlying framework

• Stable Diffusion:

Latent Diffusion Model (LDM) -- diffusion in VAE latent space, not pixel space; ~8x faster
 VAE encoder/decoder -- compress 512x512 image to 64x64x4 latent; decompress after denoising
 U-Net denoiser -- cross-attention layers incorporate text conditioning at every resolution level
 CLIP text encoder -- embeds prompt text; fed into U-Net cross-attention to guide denoising
 Classifier-Free Guidance (CFG) -- blend conditional and unconditional score; controls quality vs diversity
 CFG scale -- low (1-3): loose and diverse; high (7-15): sharp and tightly prompt-adherent

Week 4 | Sessions 16-20

Transformers for Generation & LLMs -- First Contact

Mon	Tue	Wed	Thu	Fri
S16	S17	S18	S19	S20
Transformers I -- self-attention & multi-head attention mechanism	Transformers II -- decoder-only architecture, positional encoding & KV cache	Transformers III -- autoregressive generation & sampling strategies	Transformers IV -- scaling laws, architecture variants & emergent abilities	LLMs I -- first LLM API call hands-on + pretraining objectives & web-scale data

Module 6: Transformers for Generation

Sessions 16-19

• Self-Attention Mechanism:

Attention as soft retrieval -- Query asks, Key matches, Value is the returned content
 Scaled dot-product: $\text{Attention}(Q, K, V) = \text{softmax}(QK^T / \sqrt{d_k}) * V$
 Captures long-range dependencies -- any two positions interact directly; no recurrence bottleneck
 Quadratic complexity $O(n^2)$ in sequence length -- efficient variants (FlashAttention) for long contexts
 Attention patterns -- different heads learn syntactic, semantic, and positional relations

• Multi-Head Attention:

H parallel attention heads -- each projects Q, K, V to a lower-dimensional subspace
 Each head attends to different aspects -- syntax, coreference, positional structure simultaneously
 Concatenate head outputs then linear projection back to model dimension d_{model}
 Richer representation than single-head attention of the same total compute budget

- **Positional Encoding:**

Attention is permutation-invariant -- must explicitly inject position information into tokens
 Sinusoidal encoding -- fixed; deterministic; generalises to sequences longer than seen in training
 Learned positional embeddings -- trainable; used in GPT-2; limited length generalisation
 RoPE (Rotary Position Embedding) -- encodes relative position via rotation; used in LLaMA and Mistral
 ALiBi -- linear attention bias by distance; strong extrapolation to longer sequences

- **Decoder-only Architecture:**

Causal (masked) self-attention -- each token attends only to past tokens; triangular mask enforced
 Enables autoregressive generation -- predict one token at a time, strictly left to right
 Used in GPT-2/3/4, LLaMA, Mistral -- dominant paradigm for open-ended language generation
 Layer structure -- pre-norm: RMSNorm, attention, residual; RMSNorm, FFN, residual
 KV cache -- store past key/value tensors during inference; avoids recomputation; critical for speed

- **Autoregressive Generation & Sampling:**

Generate one token at a time -- $P(x_t | x_{1...x_{t-1}})$; product gives full sequence probability
 Greedy decoding -- always pick argmax; fast but repetitive and sub-optimal
 Temperature -- divide logits by T before softmax; $T > 1$ creative, $T < 1$ focused and deterministic
 Top-k sampling -- sample only from the top k most probable tokens; removes long-tail noise
 Top-p (nucleus) sampling -- dynamic top set covering cumulative probability mass p; more adaptive
 Repetition penalty -- downweight previously generated tokens; reduces looping and repetition

- **Scaling Laws & Architecture Variants:**

Chinchilla scaling laws -- tokens = 20x parameters for compute-optimal training efficiency
 Performance scales predictably with compute C, data D, and model parameters N
 Emergent abilities -- multi-step reasoning and arithmetic appear suddenly at sufficient scale
 Mixture of Experts (MoE) -- sparse activation; Mixtral 8x7B; efficient parameter scaling
 Encoder-decoder (T5, BART) -- better for seq2seq tasks; decoder-only dominates open generation

Module 7: Large Language Models (LLMs)

Sessions 20-24

- **First LLM API Call -- hands-on before theory:**

Call GPT-4o-mini or Claude API in Python -- see the model respond in under 5 lines of code
 Set up API keys securely -- .env file + python-dotenv; never hardcode credentials
 Inspect the response object -- role, content, finish_reason, usage tokens, model ID
 Try different prompts -- observe how prompt wording changes output drastically
 This session anchors the entire LLMs module -- practical first, theory second

- **Pretraining Objectives:**

Causal Language Modelling (CLM) -- predict next token; used by GPT family; simple and scalable
 Masked Language Modelling (MLM) -- predict masked tokens; bidirectional context; BERT-style
 Span corruption -- mask and predict contiguous spans; used in T5 and UL2
 Web-scale data -- CommonCrawl, Books3, Wikipedia, GitHub, arXiv; aggressive quality filtering critical
 Data mixture -- domain balance shapes downstream capabilities; code data improves reasoning broadly

Week 5 | Sessions 21-25

Large Language Models -- Deep Dive & Prompt Engineering

Mon	Tue	Wed	Thu	Fri
S21	S22	S23	S24	S25
LLMs II -- tokenization (BPE, SentencePiece, tiktoken)	LLMs III -- supervised fine-tuning (SFT) & dataset preparation	LLMs IV -- instruction tuning & RLHF alignment	LLMs V -- open vs closed models, HuggingFace & Ollama	Prompt Eng. I -- design principles, zero-shot & few-shot learning

Module 7: LLMs -- continued

• Tokenization:

Byte-Pair Encoding (BPE) -- merge frequent byte pairs iteratively; tiktoken used by GPT-4
 SentencePiece -- language-agnostic; handles CJK, Arabic, Hindi without pre-tokenisation step
 Vocabulary size -- 32K-128K tokens; larger vocab: shorter sequences but more embedding parameters
 Tokenisation artefacts -- split words, leading spaces, case sensitivity; affects prompt design
 Special tokens -- end-of-text, user, assistant; critical for chat fine-tuning format
 Counting tokens before API calls -- tiktoken; estimate cost; prevent unexpected truncation

• Supervised Fine-Tuning (SFT):

Train on (prompt, response) pairs -- teach the model what high-quality responses look like
 Learning rate -- much smaller than pretraining (1e-5 to 5e-5); warmup + cosine decay
 Catastrophic forgetting -- full SFT may overwrite general capabilities; PEFT methods mitigate this
 Dataset quality -- 100 high-quality examples often outperform 10,000 noisy ones
 When to fine-tune vs prompt -- fine-tune for consistent format and style; prompt for flexibility

• Instruction Tuning:

Training on diverse instruction-following examples -- generalises to unseen task formats
 FLAN -- template-based reformulation of 62 NLP datasets across many task types
 Chat templates -- system/user/assistant turn structure; model must see this format during SFT
 Multi-turn dialogue -- maintaining conversation context across turns; role tags are critical

• RLHF & Alignment:

Reward Model (RM) -- trained on human preference pairs; learns to score responses as humans would
 Human preference data -- pairwise comparisons (preferred vs rejected); quality matters more than quantity
 PPO (Proximal Policy Optimisation) -- fine-tune LLM to maximise RM score; clipping prevents large updates
 KL penalty -- keeps fine-tuned model close to the reference policy; prevents reward hacking and collapse
 Alignment goal -- Helpful, Harmless, Honest (HHH); reducing harmful and sycophantic outputs
 RLHF limitations -- reward hacking; human labeller disagreement; expensive preference collection
 DPO (Direct Preference Optimisation) -- no separate RM needed; trains directly on preference pairs; read the paper for the derivation

• Open-source vs Closed Models:

Open-source -- LLaMA 3, Mistral, Phi-3, Gemma, Qwen; fine-tuneable; local and private deployment
 Closed -- GPT-4o, Claude 3.5 Sonnet, Gemini 1.5 Pro; API-only; highest capability tier currently
 HuggingFace Hub -- model cards, weights, tokeniser configs; AutoModelForCausalLM pattern
 Ollama -- run open models locally; simple REST API; great for development and privacy-sensitive data
 Selection criteria -- task complexity, latency, cost, data privacy, customisation requirements

Week 6 | Sessions 26-30

Prompt Engineering -- Completion & Multimodal Generative AI

Mon	Tue	Wed	Thu	Fri
S26	S27	S28	S29	S30
Prompt Eng. II -- chain-of-thought & advanced prompting techniques	Prompt Eng. III -- system prompts, injection attacks & prompt optimisation	Multimodal I -- text-to-image models (DALL-E, Stable Diffusion, CLIP)	Multimodal II -- image-to-text, vision-language models & VQA	Multimodal III -- audio, video generation & cross-modal learning

Module 8: Prompt Engineering

Sessions 25-27

• Prompt Design Principles:

Clarity -- unambiguous task description; specify output format, length, and tone explicitly
 Context -- provide relevant background; include examples of expected input and output pairs
 Constraints -- what to avoid, required output schema, language and style specifications
 Role assignment -- "You are a senior ML engineer..." -- shapes model behaviour consistently
 Iterative refinement -- test on diverse examples; analyse failure modes; adjust systematically

• Zero-shot & Few-shot Learning:

Zero-shot -- model performs task from description alone; relies on instruction-following capability

Few-shot -- 1-8 input-output examples in the prompt; demonstrates format and expected style
 Example selection -- diverse, representative, correctly labelled; avoid misleading patterns
 Format consistency -- examples must exactly match expected output format; model learns by mimicry
 In-context learning -- no weight updates; knowledge retrieved purely from the context window

Module 8: Prompt Engineering -- continued

Sessions 26-27

• Chain-of-Thought (CoT) Prompting:

"Let's think step by step" -- triggers explicit intermediate reasoning before the final answer
 Zero-shot CoT -- single trigger phrase; effective on arithmetic, logic, and multi-step reasoning
 Few-shot CoT -- provide full worked examples with complete reasoning chains in the prompt
 Self-consistency -- sample multiple reasoning paths; majority-vote the final answer for reliability
 Least-to-most prompting -- decompose complex problem into ordered sub-problems; solve sequentially

• Advanced Prompting Techniques:

Tree of Thought (ToT) -- explore multiple reasoning branches in parallel; evaluate and select best
 ReAct -- interleave reasoning and tool use (web search, calculator, code execution) in one prompt
 Retrieval-Augmented Prompting -- prepend retrieved context chunks; factual grounding for answers
 DSPy -- declarative prompt programming; compiles and optimises prompts automatically
 Soft prompts and prefix tuning -- trainable continuous embeddings prepended to input sequence

• System Prompts & Safety:

System prompt -- sets model persona, behaviour and constraints; persists across all conversation turns
 Prompt injection attacks -- adversarial user inputs that override system instructions; defence patterns
 Jailbreaking -- attempts to bypass safety guidelines; why alignment robustness remains hard
 Output validation -- always validate LLM output format and content before downstream system use
 Prompt optimisation -- APE (Automatic Prompt Engineer); iterative evaluation-based prompt search

Module 9: Multimodal Generative AI

Sessions 28-30

• Text-to-Image Models:

DALL-E 3 -- GPT-4 recaptioning for dense prompt adherence; diffusion backbone for generation
 Stable Diffusion -- open-source latent diffusion; massive community fine-tune and ControlNet ecosystem
 CLIP (Contrastive Language-Image Pretraining) -- aligns text and image in shared embedding space
 Contrastive training -- 400M image-text pairs; maximise similarity of matched pairs; cosine objective
 Prompt engineering for images -- art style, lighting, camera angle, composition, negative prompts
 ControlNet -- conditioning on depth map, edge map, or pose; precise spatial control over output

• Image-to-Text Models:

Image captioning -- describe image content in natural language; encoder-decoder architecture
 Visual Question Answering (VQA) -- answer free-form questions about image content
 Vision-Language Models -- LLaVA, GPT-4o Vision, Gemini; image tokens projected into LLM space
 BLIP-2 -- Q-Former bridges frozen vision encoder and frozen LLM; efficient cross-modal alignment
 OCR capabilities -- reading text within images; document understanding and structured extraction

• Audio, Video Generation & Cross-modal Learning:

Text-to-speech (TTS) -- Tacotron 2, VITS; mel-spectrogram + neural vocoder pipeline
 MusicGen -- autoregressive on EnCodec audio tokens; conditioned on text and melody
 Voice cloning -- few seconds of reference audio maps to a personalised voice embedding for TTS
 Video generation -- Sora (diffusion transformer, space-time patch tokens); Runway Gen-2 for practical use
 Cross-modal contrastive learning -- align embeddings from different modalities via matched pairs
 Unified tokenisation -- treat images (VQ-VAE tokens), audio (codec tokens), text as one sequence

Week 7 | Sessions 31-35

Fine-Tuning, Adaptation & Evaluation

Mon	Tue	Wed	Thu	Fri
S31	S32	S33	S34	S35

Fine-Tuning I -- full fine-tuning & dataset preparation	Fine-Tuning II -- LoRA, QLoRA & PEFT methods	Fine-Tuning III -- domain adaptation & instruction fine-tuning	Evaluation I -- metrics, LLM-as-judge & hallucination detection	Evaluation II -- bias, fairness, toxicity & alignment problems
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Module 10: Fine-Tuning & Adaptation

Sessions 31-33

• Full Fine-Tuning:

- Update all parameters -- most flexible; requires proportional compute to original pretraining
- Memory requirements -- model weights + gradients + optimiser states; approximately 4x model size in FP32
- Dataset preparation -- instruction format, quality filtering, deduplication, train/val split
- Evaluation -- held-out task metrics; check for capability regression on general benchmarks
- When appropriate -- small models, abundant labelled data, domain very different from pretraining

• LoRA (Low-Rank Adaptation):

- Inject trainable rank-r matrices into frozen attention weight matrices of the base model
- $W_{\text{new}} = W + BA$; B has shape (d, r), A has shape (r, k); only A and B are trained; base W frozen
- Parameter reduction -- $r=8$ gives approximately 99% fewer trainable parameters vs full fine-tuning
- Rank selection -- $r=4$ to 16 typical; higher r gives more capacity; diminishing returns beyond 64
- Target modules -- q_{proj} , v_{proj} in attention layers; sometimes also k_{proj} , o_{proj} , FFN layers
- Merging at inference -- $W_{\text{new}} = W + BA$; zero latency overhead compared to the base model

• QLoRA:

- 4-bit quantisation of base model (NF4 format) -- dramatically reduces memory footprint
- LoRA adapters computed in BFloat16 -- high-precision gradients despite quantised base weights
- Double quantisation -- quantise the quantisation constants for further memory savings
- Paged optimisers -- CPU offload for optimiser states; enables 70B models on single consumer GPU
- Practical impact -- fine-tune 7B to 70B models on a single GPU with 24GB VRAM

• Other PEFT Methods:

- Prefix Tuning -- prepend trainable soft token embeddings to K and V; no architecture change
- Prompt Tuning -- trainable task prefix embedding only; lightest-weight PEFT approach
- Adapter layers -- small bottleneck MLP inserted between transformer sub-layers; only adapters trained
- IA3 -- scales attention keys, values and FFN activations; very few parameters, strong performance

• Domain Adaptation & Instruction Fine-Tuning:

- Continued pretraining -- further train on unlabelled domain text; adapts vocabulary distribution
- Domain data sources -- medical (PubMed), legal (court opinions), finance, code (GitHub)
- Instruction datasets -- Alpaca, Dolly, OpenAssistant, ShareGPT; quality over quantity always
- Prompt templates -- consistent format for all training examples; must match inference format exactly
- Evaluation -- MT-Bench (multi-turn); MMLU (knowledge breadth); HumanEval (code generation)

Module 11: Evaluation & Safety

Sessions 34-35

• Evaluation Metrics:

- BLEU -- n-gram precision; designed for translation; poor proxy for open-ended generation quality
- ROUGE -- recall-oriented; used for summarisation; ROUGE-L captures longest common subsequence
- Perplexity -- how well model predicts held-out text; lower is better; not always task-aligned
- BERTScore -- semantic similarity via contextual embeddings; better than surface n-gram overlap
- FID and IS -- Frechet Inception Distance and Inception Score; standard for image generation quality
- LLM-as-judge -- GPT-4 or Claude evaluates outputs on defined criteria; scalable evaluation proxy

• Hallucinations:

- Factual hallucination -- confident generation of false or unverifiable information
- Faithfulness hallucination -- response contradicts the provided source context
- Causes -- overconfident next-token prediction; knowledge gaps; reward hacking in RLHF
- Detection -- NLI-based consistency checking; retrieval verification; TruthfulQA benchmark
- Mitigation -- RAG for factual queries; citation requirements; uncertainty quantification

• Bias, Fairness & Safety:

- Social biases -- gender, racial, religious stereotypes encoded from web-scale training data
- Measurement benchmarks -- WinoBias, StereoSet, BBQ (Bias Benchmark for QA)
- Toxic content categories -- hate speech, violence, self-harm; safety classifiers (Llama Guard)
- Constitutional AI -- model uses written principles to self-critique and revise its own outputs

Red-teaming -- structured adversarial testing to find safety failures before deployment

- **Alignment Problems:**

Goodhart's Law -- when a measure becomes a target it ceases to be a good measure

Reward hacking -- model exploits the reward function without satisfying the true objective

Sycophancy -- model agrees with user even when wrong; artefact of human-preference training signal

Specification gaming -- maximising proxy objective while violating true human intent

Ongoing research -- interpretability, scalable oversight, debate, iterated amplification

Week 8 | Sessions 36-40

Deployment, RAG in Depth & Capstone Kickoff

Mon	Tue	Wed	Thu	Fri
S36	S37	S38	S39	S40
Deployment I -- API-based deployment & FastAPI for LLM serving	Deployment II -- quantisation, KV cache, vLLM & latency optimisation	Deployment III -- real-world applications, monitoring & cost optimisation	RAG in Depth -- architecture, vector DBs, chunking, reranking & evaluation	Agents, Memory in LLMs & Capstone Kickoff -- project brief & team formation

Module 12: Deployment & Applications

Sessions 36-38

- **API-based Deployment:**

OpenAI API -- GPT-4o, structured outputs, function calling, vision, assistants API

Anthropic API -- Claude; tool use, extended thinking, vision, 200K token context window

HuggingFace Inference API -- open models without self-hosting; serverless and dedicated endpoints

Rate limits and cost management -- tokens/min limits; estimate cost before calling; set usage alerts

API key security -- .env file + python-dotenv; never hardcode in source; rotate keys regularly

Structured outputs -- JSON mode, response_format schema; reliable parsing for downstream systems

- **FastAPI for LLM Serving:**

Loading open-source models -- AutoModelForCausalLM on startup; singleton pattern to avoid reload

Streaming responses -- Server-Sent Events (SSE); token-by-token output for low perceived latency

Request schema -- Pydantic models; input validation; structured error responses (422, 500)

Authentication -- API key middleware; bearer token header; per-key rate limiting

Async endpoints -- non-blocking inference; handle multiple concurrent generation requests

Swagger UI at /docs -- auto-generated interactive API documentation; share with team instantly

- **Latency Optimisation:**

Quantisation -- INT8 (bitsandbytes), GPTQ, AWQ; 2-4x smaller model with faster inference

KV cache -- store past attention key/value tensors; avoids $O(n^2)$ recomputation per token

Speculative decoding -- small draft model proposes tokens; large model verifies batch in parallel

vLLM -- PagedAttention manages KV cache memory like OS paging; high-throughput production serving

Flash Attention -- IO-aware attention; avoids materialising full $O(n^2)$ matrix in GPU memory

Continuous batching -- dynamically batch requests of different lengths; maximise GPU utilisation

- **Real-world Applications & Cost Optimisation:**

Chatbots and assistants -- multi-turn conversation; tool use; conversation memory management

Code generation -- GitHub Copilot pattern; context window management; edit distance metrics

Document processing -- extraction, summarisation, classification; structured output pipelines

Monitoring and drift -- log requests/responses; track latency, error rate, and output quality

Token counting -- tiktoken; estimate cost before calling; cache identical prompt responses

Model selection -- GPT-4o-mini or Claude Haiku for simple tasks; frontier models for complex reasoning

Prompt compression -- LLMingua; remove redundant tokens while preserving semantic meaning

Module 13: RAG, Agents & Future Directions

Sessions 39-40

- **Retrieval-Augmented Generation (RAG) -- core pipeline:**

Motivation -- LLM knowledge frozen at training cutoff; hallucinations on current and factual queries

Architecture -- retriever finds relevant documents; LLM generates a grounded response from them

Dense retrieval -- DPR, Contriever; encode query and docs to vectors; cosine similarity search
 Sparse retrieval -- BM25; TF-IDF based; efficient; strong baseline especially for keyword queries
 Vector databases -- FAISS (local/free), Chroma (local dev), Pinecone/Qdrant (managed cloud); ANN search
 Chunking strategy -- fixed size, sentence-level, semantic; chunk overlap maintains context continuity
 Reranking -- cross-encoder reranks top-k retrieved chunks for precision before passing to LLM
 Hybrid retrieval -- combine dense + sparse scores; gets benefits of both; standard in production RAG
 RAGAS evaluation -- faithfulness, answer relevancy, context precision, context recall
 Advanced RAG (self-study) -- HyDE, multi-hop RAG, corrective RAG; reference links in course repo

• Agents and Tool Use:

LLM as reasoning engine -- decides which action to take given a goal and available tools
 Tool calling -- structured function calls: web search, calculator, code interpreter, external APIs
 ReAct pattern -- Reasoning + Acting; interleaved thought and action traces in the context window
 LangChain and LlamaIndex -- orchestration frameworks; chains, agents, memory components
 Multi-agent systems -- planner agent + specialised executor agents; roles and handoffs

• Memory in LLMs:

In-context memory -- everything in the context window; bounded by token limit (4K to 1M)
 External memory -- vector store; retrieve relevant past interactions via similarity search
 Episodic memory -- selective storage of important context; recency and relevance scoring
 Long-context models -- Gemini 1.5 (1M tokens), Claude (200K); tradeoffs in cost and latency

• Future Directions:

Multimodal foundation models -- any-to-any generation; embodied and action AI models
 Efficient architectures -- Mamba (state space models); MoE (Mixture of Experts) at scale
 AI agents at scale -- autonomous multi-step task completion; long-horizon planning
 Interpretability -- understanding what LLMs know and how; mechanistic interpretability research
 Regulation and governance -- EU AI Act; model cards; responsible disclosure; output watermarking

Week 9 | Sessions 41-45

Capstone & Career Week

Mon	Tue	Wed	Thu	Fri
S41	S42	S43	S44	S45
Capstone Work -- mentored project development & doubt-solving (session 1)	Capstone Work -- mentored project development & doubt-solving (session 2)	Resume, Portfolio & Career Readiness Workshop	Final Presentations -- team demos, Q&A & peer review	Course Wrap-up -- feedback, certificates & next steps

Capstone Project (Sessions 41-45)

Sessions 41-45

• End-to-end Generative AI application delivery:

Teams build a production-grade Gen AI application -- chatbot, RAG system, fine-tuned model API, or multimodal app
 All work on the organisation GitHub repo -- PRs used for mentor review and integration throughout
 Mentor-led doubt-solving sessions (S41 and S42) -- feedback delivered via PR comments
 Mid-capstone checkpoint -- progress review; mentor merges or requests changes

• Final Presentation (Session 44):

10-minute team demo + 5-minute Q&A
 Present: problem statement, model choice and architecture, results, limitations, deployment
 Peer review -- structured feedback form for cross-team assessment
 Certificate of Completion issued upon successful delivery

Resume, Portfolio & Career Readiness Workshop (Session 43)

Session 43

• Gen AI Resume Structure:

One-page format for 0-3 years experience; two-page maximum for senior roles

Skills section -- Python, PyTorch, HuggingFace, LangChain, FastAPI, Docker, cloud platforms

Projects section -- problem, model and approach, result, impact (quantified where possible)

ATS optimisation -- keyword alignment with Gen AI job descriptions (LLM, RAG, fine-tuning, prompt engineering)

- **GitHub Portfolio:**

By this point: 9 weeks of daily PRs on the org repo -- a live, reviewable learning track record

Capstone repo under the org -- deployed Gen AI application with a live demo link

Personal profile README -- pinned repos, tech stack summary, deployed project links

Contribution graph -- consistent activity signals reliability and commitment to recruiters

README structure for each project -- problem, model used, approach, results, how to run

- **LinkedIn Optimisation:**

Headline -- "Generative AI Engineer | Python | HuggingFace | LangChain | FastAPI" style

About section -- 3-5 sentences: background, what you build, key tools and what you are seeking

Featured section -- link to deployed app, org GitHub repo, or a demo video

Skills and endorsements -- request endorsements from cohort peers for Gen AI, LLMs, Python

- **Interview Guidance:**

Technical rounds -- explain model architectures (Transformer, VAE, GAN, Diffusion), tradeoffs and training dynamics

LLM case studies -- when to use RAG vs fine-tuning; how to handle hallucinations in production

Coding rounds -- Python, PyTorch, HuggingFace; implement attention mechanism; write a training loop

Behavioural -- STAR method; align stories to Gen AI project experience from the capstone

Common questions: attention mechanism, RLHF, LoRA vs full fine-tuning, latency optimisation strategies