**Exam Questions (MAL2, Spring 2025)**

These questions are designed to encourage discussion and demonstration of understanding beyond simple recall.

1. **Core Training Mechanism and Gradient Issues** *(Lecture 2)*: Explain the fundamental process of training a deep neural network by minimizing a loss function using gradient descent. Describe the backpropagation algorithm and how it efficiently calculates the gradients needed for parameter updates. Discuss the phenomenon of vanishing and exploding gradients, which can hinder training stability and convergence, and explain how factors like the choice of activation functions can influence these gradient issues.

2. **Improving Training Stability and Preventing Overfitting** *(Lecture 2)*: Discuss how advanced optimizers (beyond basic SGD) such as Momentum or Adam improve the efficiency and stability of the parameter updates during training. Explain the importance of dynamically adjusting the learning rate through learning rate scheduling. Furthermore, explain how regularization techniques such as Dropout and Early Stopping are used to prevent overfitting and improve the generalization performance of deep neural networks.

3. **Convolutional Neural Networks and Feature Extraction** *(Lecture 3)*: Explain how convolutional layers operate, including the role of filters, kernels, and receptive fields. How do CNNs learn hierarchical feature representations? Additionally, describe the purpose and effect of pooling layers such as max pooling.

4. **Autoencoders and Representation Learning** *(Lecture 4)*: What is an autoencoder, and how does it learn useful representations of the input data? Beyond dimensionality reduction, describe at least one practical application of autoencoders, such as denoising, anomaly detection, or unsupervised pretraining.

5. **Modern Generative Models: GANs and Diffusion** *(Lectures 5 and 10)*: Describe the architecture and training process of Generative Adversarial Networks (GANs), highlighting the competition between generator and discriminator. If time permits, explain the concept behind Diffusion Models, focusing on the forward noising and reverse denoising process, and compare the key differences between how GANs and Diffusion Models generate samples.

6. **Recurrent Neural Networks (RNNs) and Memory** *(Lecture 6)*: How do recurrent connections in RNNs allow the network to process sequential data? Discuss the limitations of simple RNNs for long-term dependencies and explain how architectures like LSTMs and GRUs use gating mechanisms to address these issues.

7. **Text Generation with RNNs and Embeddings** *(Lecture 7)*: Explain how a character-level RNN (Char-RNN) can be trained to generate text. Describe the role of character embeddings and the softmax output layer. How does temperature sampling influence the creativity and coherence of the generated text?

8. **Large Language Models and Transformers** *(Lecture 8)*: Explain the encoder-decoder architecture of transformers and the purpose of attention mechanisms. How does self-attention work, and why was it a breakthrough that enabled the development of large language models (LLMs)? Describe one advantage of transformer-based models over earlier RNN-based language models.

9. **Reinforcement Learning Paradigms** *(Lecture 9)*: Describe the components of a reinforcement learning system: agent, environment, states, actions, rewards, and returns. Compare value-based methods (such as Q-learning/DQN) with policy-based methods (such as policy gradients) and explain how each approach learns an optimal policy.
10. **New Frontiers in AI, Agentic Systems, and Ethical Challenges** *(Lecture 10)*: Discuss emerging directions in deep learning, particularly Large Language Models (LLMs) and generative models. What are the known limitations of frontier AI systems, such as hallucinations, generalization issues, and uncertainty? Identify key ethical challenges in AI systems in the real world.