Final Exam

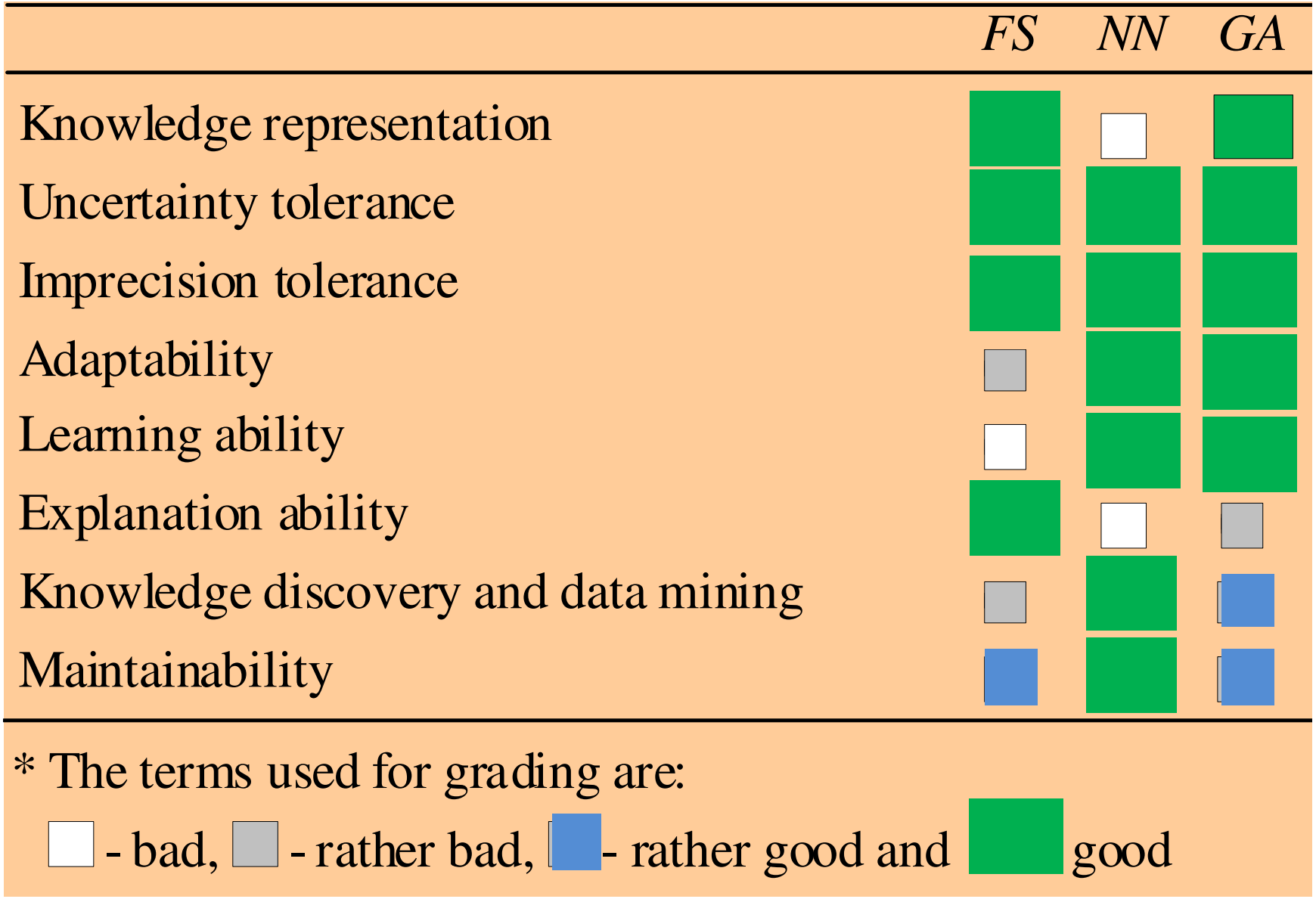
Question on your Fuzzy presentation {F. Controller, F. Expert Sys., Solving F. Ineq.}

Question on your Nets Presentations {Hopefield, SVM, Comptetive Learning, Winner- take all learning for classification}

Hybrid Systems

- A **hybrid intelligent system** is one that combines at least two intelligent technologies.
  - For example, combining a neural network with a fuzzy system results in a hybrid neuro-fuzzy system.
- The combination of:
  - fuzzy logic,
  - neural networks and
  - evolutionary computation
- Soft Computing is an emerging approach to building hybrid intelligent systems capable of reasoning and learning in an uncertain and imprecise environment.

Comparison of Fuzzy Systems, Neural Networks and Genetic Algorithms



Neuro-fuzzy systems

- Fuzzy logic and neural networks are natural complementary tools in building intelligent systems.

- While neural networks are low-level computational structures that perform well when dealing with raw data, fuzzy logic deals with reasoning on a higher level, using linguistic information acquired from domain experts.

- However, fuzzy systems lack the ability to learn and cannot adjust themselves to a new environment.
  - On the other hand, although neural networks can learn, they are “Black box” to the user.

Neuro-fuzzy systems

- Integrated neuro-fuzzy systems can combine the parallel computation and learning abilities of neural networks with the human-like knowledge representation and explanation abilities of fuzzy systems.

- As a result, neural networks become more understandable, while fuzzy systems become capable of learning.

Neuro-fuzzy systems

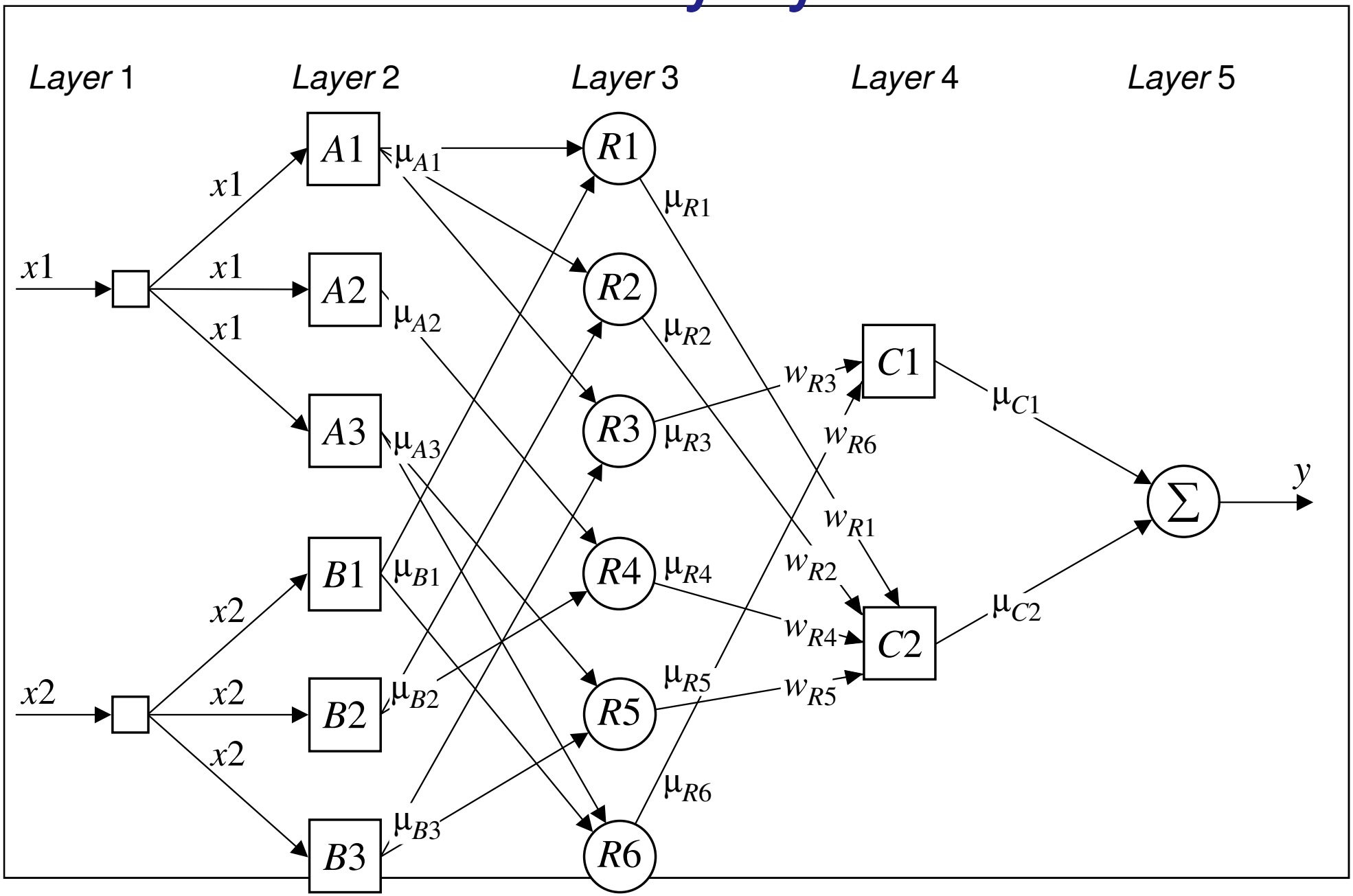
- A neuro-fuzzy system is a neural network which is functionally equivalent to a fuzzy inference model.
- Neuro-Fuzzy System can be trained to develop IF-THEN fuzzy rules and determine membership functions for input and output variables of the system.
- Expert knowledge can be incorporated into the structure of the neuro-fuzzy system.
- At the same time, the connectionist structure avoids fuzzy inference, which requires a computational work.

Neuro-fuzzy systems

- The structure of a neuro-fuzzy system is similar to a multi-layer neural network.

- In general, a neuro-fuzzy system has:
  - input and output layers,
  - and three hidden layers
    - that represent membership functions and fuzzy rules.

Neuro-fuzzy systems



Neuro-fuzzy systems

Each layer in the neuro-fuzzy system is associated with a particular step in the fuzzy inference process.

***Layer* 1** is the **input layer**. Each neuron in this layer transmits external crisp signals directly to the next layer.

***Layer* 2** is the **fuzzification layer**.

- Neurons in this layer represent fuzzy sets used in the antecedents of fuzzy rules.
- A fuzzification neuron receives a crisp input and determines the degree to which this input belongs to the neuron's fuzzy set.

***Layer* 3** is the **fuzzy rule layer**.

1. Each neuron in this layer corresponds to a single fuzzy rule.
2. A fuzzy rule neuron receives inputs from the fuzzification neurons that represent fuzzy sets in the rule antecedents.

***Layer* 4** is the **output membership layer**.

Neurons in this layer represent fuzzy sets used in the consequent of fuzzy rules.

An output membership neuron combines all its inputs by using the fuzzy operation **union**.

***Layer*5** is the **defuzzification layer**.

Each neuron in this layer represents a single output of the neuro-fuzzy system. It takes the output fuzzy sets clipped by the respective integrated firing strengths and combines them into a single fuzzy set.

Neuro-fuzzy systems can apply standard defuzzification methods

How does a neuro-fuzzy system learn?

A neuro-fuzzy system is essentially a multi-layer neural network, can apply any learning algorithms developed for neural networks, including the back-propagation algorithm.

- When a training input-output example is presented to the system, the back-propagation algorithm computes the system output and compares it with the desired output of the training example.
  - The error is propagated backwards through the network from the output layer to the input layer.
  - The neuron activation functions are modified as the error is propagated.
  - To determine the necessary modifications, the back-propagation algorithm differentiates the activation functions of the neurons.