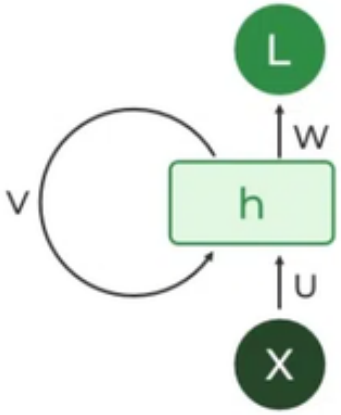
RNN

Recurrent Neural Networks (RNNs) are a type of neural network designed to handle sequential data, such as text, time series, and speech. Unlike traditional neural networks that treat each input independently, RNNs have a "memory" that allows them to retain information about previous inputs.

The Recurrent Formula

The core operation of an RNN can be described by the following formula:



$$h_t = f(W * h_{t-1} + U * x_t + b)$$

Where:

- `h_t` is the hidden state at time step *t*.
- `h_{t-1}` is the hidden state at the previous time step.
- `x_t` is the input at time step *t*.
- `W` is the weight matrix for the recurrent connections.
- `U` is the weight matrix for the input connections.

- `b` is the bias.
- `f` is an activation function (e.g., tanh, ReLU).

Types of RNN Architectures

- **One-to-Many:** One input produces a sequence of outputs (e.g., image captioning).
- **Many-to-One:** A sequence of inputs produces one output (e.g., sentiment analysis).
- **Many-to-Many:** A sequence of inputs produces a sequence of outputs (e.g., machine translation).

Challenges with Basic RNNs Vanishing and Exploding Gradients

Basic RNNs suffer from the vanishing gradient problem, where the gradients used for training become very small over long sequences, making it difficult for the network to learn long-range dependencies. The opposite problem, exploding gradients, can also occur, where the gradients become very large, leading to unstable training.

Solutions: LSTMs and GRUs

To address these challenges, more sophisticated RNN architectures were developed:

- **Long Short-Term Memory (LSTM):** LSTMs introduce "gates" that control the flow of information into and out of the cell state, allowing them to selectively remember or forget information over long sequences.
- **Gated Recurrent Unit (GRU):** GRUs are a simplified version of LSTMs with fewer gates, making them computationally more efficient.

Applications of RNNs

Natural Language Processing (NLP):

- Machine translation
- Text generation
- Sentiment analysis
- Speech recognition

Time Series Analysis:

- Stock price prediction
- Weather forecasting

Video Processing:

- Action recognition
- Video captioning