Session 1: LSTMs for Earth Observation Time Series

Theory, Concepts, and Interactive Demos

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Welcome & Agenda

- **Duration:** 1.5 hours (90 minutes)
- **Plan:**
  - 0–10 min: EO time series context
  - 10–30 min: RNN basics & vanishing gradient
  - 30–60 min: LSTM architecture deep-dive (gates, cell state)
  - 60–80 min: EO applications (Mindanao drought, phenology)
  - 80–90 min: Q&A, transition to Lab (Session 2)

Learning Objectives

- Understand EO time series (NDVI, rainfall, temperature, SAR backscatter)
- Explain RNN limitations (vanishing/exploding gradients)
- Describe LSTM internals (input/forget/output gates, cell state)
- Connect LSTMs to EO tasks (drought, yield, phenology)

EO Time Series Context

What is EO Time Series?

- Repeated observations over the same AOI
- Examples: NDVI monthly means, SAR backscatter weekly, climate forcings
- Why it matters: seasonality, trends, anomalies

Typical EO Inputs for Drought

- NDVI (vegetation health)
- Rainfall (CHIRPS)
- Temperature (ERA5, station data)
- ONI/ENSO index (large-scale climate driver)

RNN Basics & Limitations

Recurrent Neural Networks (RNNs)

- Designed for sequences: maintain hidden state across time
- Learn temporal dependencies

The Vanishing Gradient Problem

- Gradients shrink across long sequences → poor long-range memory
- Results: cannot learn seasonal/annual dependencies reliably

Visual: Gradient Decay (Concept)

```
flowchart LR
  x1[Input t-3] --> H1[Hidden t-3]
  x2[Input t-2] --> H2[Hidden t-2]
  x3[Input t-1] --> H3[Hidden t-1]
  x4[Input t] --> H4[Hidden t]
  H1 --> H2 --> H3 --> H4
  classDef f stroke:#2C5F77,stroke-width:2px
```

- As sequence length increases, gradient signal fades

LSTM Architecture

Idea

- Add a “cell state” highway with gates to regulate information flow

Components

- Input gate: write new information
- Forget gate: decide what to keep/discard
- Output gate: produce relevant hidden state

LSTM Gates (Conceptual)

- Input gate: how much of new candidate state to add
- Forget gate: how much of previous cell state to keep
- Output gate: how much of cell state to expose as hidden state

```
flowchart LR
  subgraph LSTM
    C[Cell State]
    I[Input Gate]
    F[Forget Gate]
    O[Output Gate]
  end
  I --> C
  F --> C
  C --> O
```

Why LSTM for EO?

- Captures seasonal cycles and lags (e.g., rainfall → NDVI response)
- Handles noisy and irregular sequences better than vanilla RNNs
- Supports multi-variate inputs (NDVI + rainfall + temp + ONI)

EO Applications

Mindanao Drought Monitoring (Case)

- Inputs: NDVI, rainfall, temperature, ONI
- Output: drought index/severity forecast (1-month ahead)
- Benefits: early warning for agriculture

Other Examples

- Phenology (crop calendars)
- Yield estimation
- Land cover change dynamics

Demo Orientation (10 min)

- Open in Colab:
  - `course_site/day4/notebooks/day4_session1_lstm_demo_STUDENT.ipynb`
  - `course_site/day4/notebooks/day4_session1_lstm_demo_INSTRUCTOR.ipynb`
- Objectives:
  - Visualize a simple sequence
  - Observe RNN vs LSTM behavior
  - See impact of sequence length on performance

Key Takeaways

- LSTMs mitigate vanishing gradients using gates + cell state
- Perfect match for EO time series with seasonal signals
- Foundation for Session 2 hands-on drought lab

Q&A and Transition

- Questions on gates, sequence lengths, multi-variate inputs
- Move to Session 2 lab (2.5 hours)