Foundation Model for Real-Time Model Selection and Fitting

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Submission ID: 80

Motivations

Complex Data Analysis

- Time series data ubiquitous in science and manufacturing
- Datasets often have high dimensionality

Demands of Data Acquisition

- Exponential growth in data from large-scale surveys and measurement methods
- Requirement for real-time analysis in monitoring and control applications

Scalable and Efficient Analysis

- Compact model suitable for deployment on hardware platforms
- Ideal for real-time analysis in autonomous systems

Leveraging Machine Learning

- Incorporating physical constraints enhances model reliability and interpretability
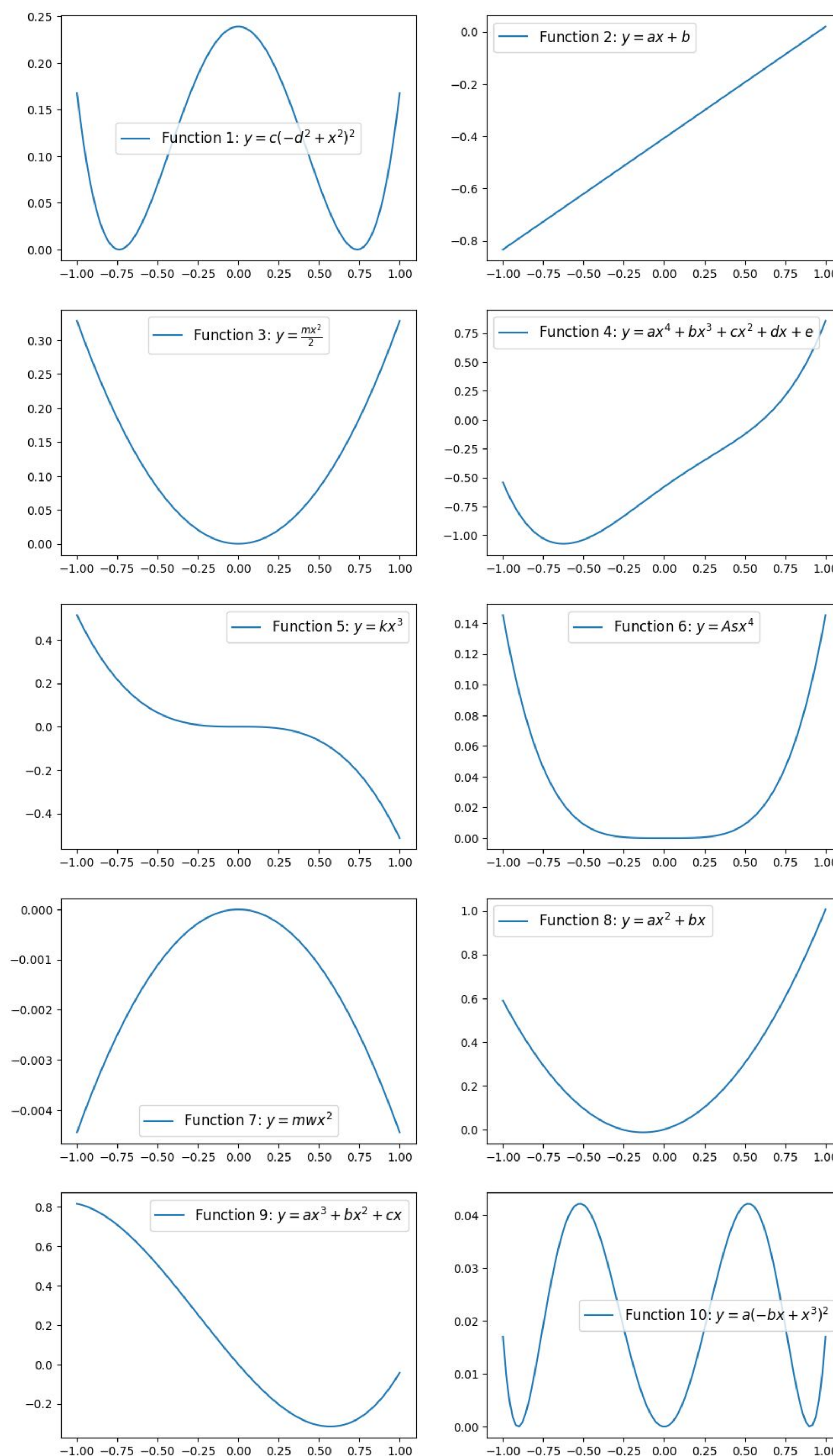- Adaptive function selection allows for flexible modeling across various phenomena

Architecture with CNNs and physical constraints to facilitate selection and generation of function forms to fit underlying data
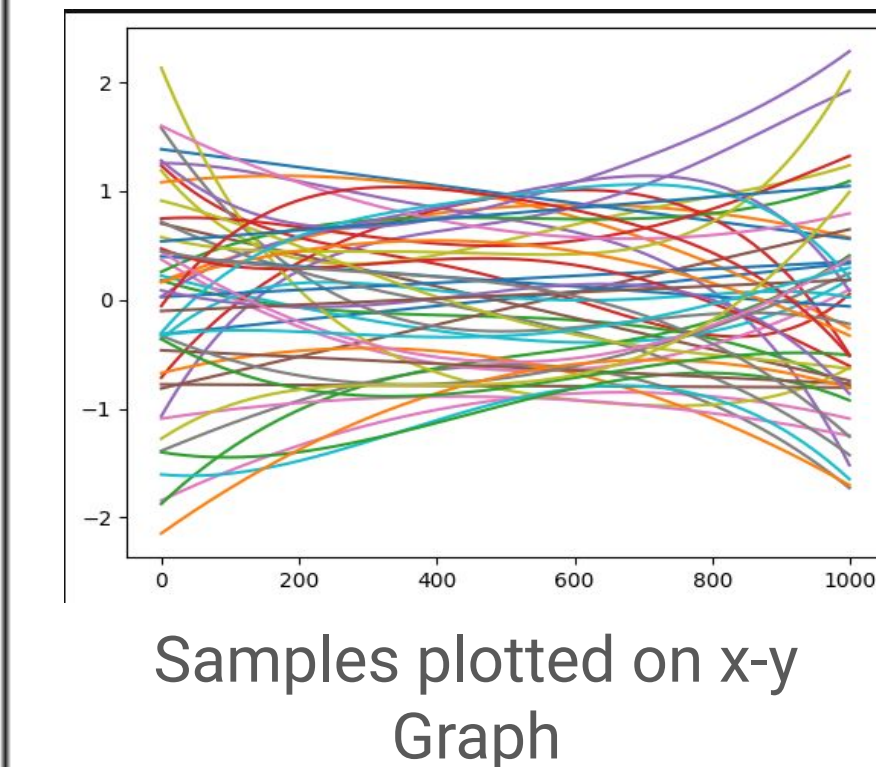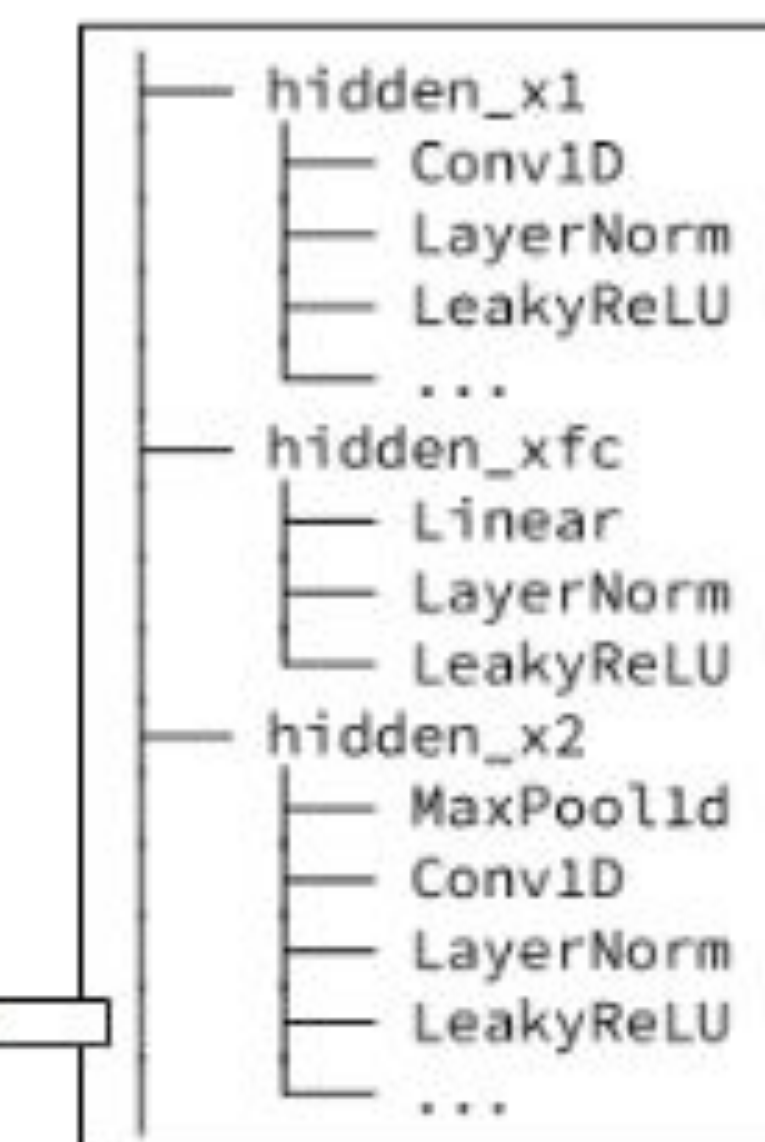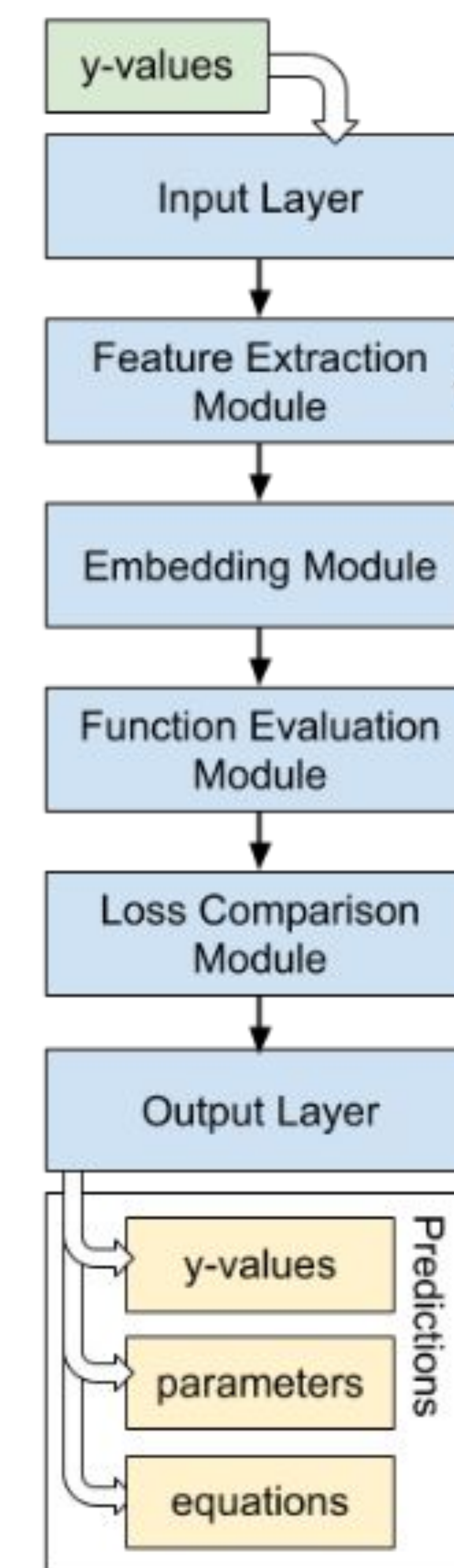
Methods

Data

- Grounded in a collection of 9 common mathematical functions
- Maximum of 5 parameters with form f(x)
- Parameters randomly generated within predefined ranges for each function
- Y-values generated by evaluating functions with parameters over fixed range (x-values)
- Large dataset of y-value sets with 10,000 samples per function

Function 1: $y = c(-d^2 + x^2)^2$

Function 2: $y = ax + b$

Function 3: $y = \frac{mx^2}{2}$

Function 4: $y = ax^4 + bx^3 + cx^2 + dx + e$

Function 5: $y = kx^3$

Function 6: $y = Asx^4$

Function 7: $y = mwx^2$

Function 8: $y = ax^2 + bx$

Function 9: $y = ax^3 + bx^2 + cx$

Function 10: $y = a(-bx + x^3)^2$

Model Process

Samples plotted on x-y Graph

Handling Noisy Data

- Layer normalization after each Conv1D layer
- Adaptive Pooling (AdaptiveAvgPool1d, MaxPool1d)
- Softmax weighting for model output
- Gradient clipping in training (max_norm=1.0)

Training

- Composite loss of parameter loss and y-value loss
- Dynamic loss weighing controlled by scheduled lambda
- Shift focus from parameters to y-values during training

Evaluation

Model accurate in predicting y-values and parameters, generating function forms fitting underlying data

Model evaluation reconstructions on x-y graph
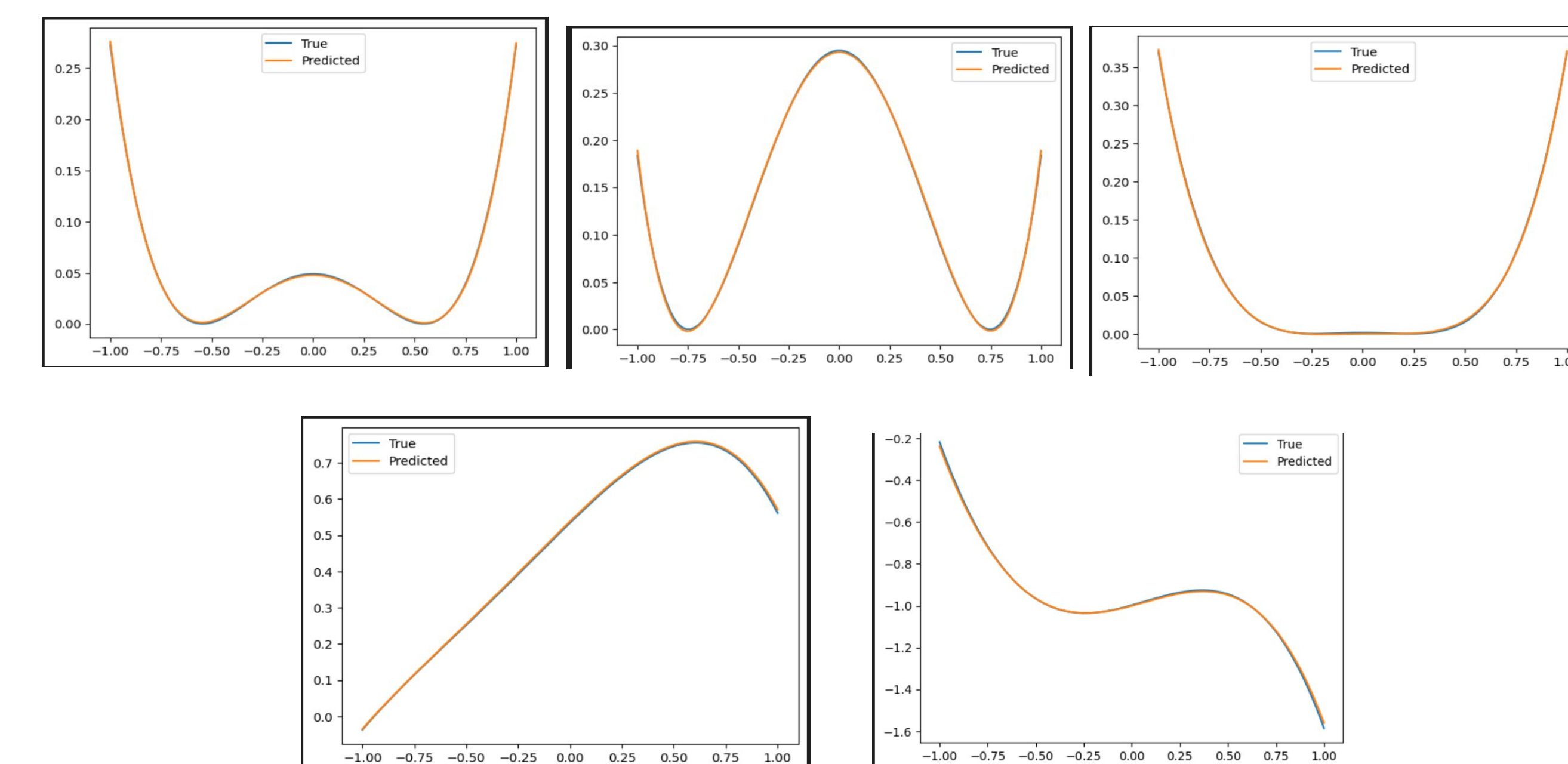
Key Features

Extensible Architecture

- Expandable function bank
- Symbolic math libraries for function evaluation
- Processes input data of varying sizes

Flexibility in Function Selection

- Works with multiple functions simultaneously
- Selects the most appropriate function for given input data
- Handle functions with varying numbers of parameters

Multi-Output Prediction

- Generates parameters for multiple functions
- Returns applicable formula for underlying data
- Computes losses for each function

Compact Solution

- Compact model suitable for deployment on hardware platforms
- Ideal for real-time processing in monitoring and control applications

Further Study

- Expand function bank for more applicable formulas
- Accommodate more parameters
- Dynamic generation of candidate functions
- Apply model to specific real-world context
- Deploy on hardware platforms for further use(ex. FPGAs)