System Architecture Explanation (ECGenius)

This system represents an ontology-driven, clinically aware ECG interpretation framework that integrates deep learning with medical reasoning, triage logic, and patient context. The workflow proceeds through the following stages:

1. Raw 12-Lead ECG Signal Input

The system begins with the acquisition of a standard 12-lead ECG waveform, representing raw electrical activity of the heart over time. This signal serves as the primary physiological input and contains information related to cardiac rhythm, conduction, ischemia, and structural abnormalities.

2. Preprocessing Module

Before analysis, the raw ECG signal undergoes preprocessing to improve signal quality and standardization. This includes:

- Removal of baseline wander and high-frequency noise using digital filters
- Normalization of signal amplitude to ensure consistency across recordings
- Lead alignment and segmentation to standardize temporal structure

This step ensures that the deep learning model receives clean, uniform input data.

3. Deep Learning Model (CNN / CNN + Transformer)

The preprocessed ECG is fed into a deep learning model, typically a convolutional neural network (CNN) or a hybrid CNN-Transformer architecture. The model extracts morphological and temporal features from the ECG waveform.

The output layer uses sigmoid activation, enabling multi-label prediction, where multiple ECG conditions can be detected simultaneously. For example:

- Atrial fibrillation probability

- Normal sinus rhythm probability
- (Future expansion: STEMI, LVH, AV block, etc.)

Each output represents an independent probability rather than a single mutually exclusive class.

4. Ontology Layer

The predicted labels from the AI model are interpreted through a clinical ontology. This ontology defines:

- Hierarchical relationships between ECG findings
- Parent-child structures (e.g., Rhythm Disorders → Atrial Fibrillation)
- Clinical categories such as rhythm abnormalities, hemodynamic disorders, ischemic syndromes, and conduction blocks

The ontology provides semantic meaning and clinical organization to the model outputs.

5. Rules and Triage Engine

The ontology-interpreted predictions are passed to a rule-based and triage engine, which applies medical logic and safety constraints. This includes:

- Mutual exclusion rules (e.g., normal rhythm cannot coexist with atrial fibrillation)
- Precedence rules that prioritize life-threatening conditions over benign findings
- Derived diagnosis rules that combine multiple findings
- Assignment of triage priority (Tier 1: life-threatening, Tier 2: urgent, Tier 3: non-urgent)

This layer ensures clinical consistency and risk awareness.

6. Patient History Module

In parallel, the system collects relevant patient history and symptom data, such as:

- Palpitations, dizziness, or syncope

- Postural blood pressure changes
- Current medications or known comorbidities

This contextual information is essential for differentiating ECG findings and supporting accurate diagnosis.

7. Decision Fusion Box

The decision fusion module integrates all available information:

- AI-generated probabilities
- Ontology constraints
- Rule-based clinical logic
- Patient history inputs

By combining these elements, the system confirms, refines, or downgrades diagnoses and resolves conflicts between competing interpretations.

8. Final Clinical Output

The final output is a clinically interpretable decision summary, which includes:

- Primary diagnosis
- Differential diagnoses
- Assigned triage priority
- Transparent explanation of the reasoning process

This output is designed to support clinicians by providing explainable, guideline-aware decision support rather than a black-box prediction.