

Software Design Specification

AI Inbound Calling Agent

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Definition of Terms, Acronyms and Abbreviations.

Term	Description
ASR	Automatic Speech Recognition
NLU	Natural Language Understanding
TTS	Text-to-Speech
KG	Knowledge Graph
GraphRAG	Graph-based Retrieval-Augmented Generation
OTP	One-Time Password
VoIP	Voice over Internet Protocol.
PTSN	Public Switched Telephone Network
TLS	Transport Layer Security
SRTP	Secure Real-Time Transport Protocol
GDPR	General Data Protection Regulation
PDPL	Pakistan Personal Data Protection Law
HIPAA	Health Insurance Portability and Accountability Act

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1. Introduction

1.1 Purpose of Document

This Software Design Specification (SDD) defines the architectural, subsystem, and component-level design of the AI Inbound Calling Agent developed for the University of Sargodha (UOS). It serves as a blueprint for developers, system architects, testers, and evaluators to understand the system's internal structure, module interactions, data flows, and design strategies.

The project follows a modular, component-based, object-oriented design methodology

1.2 Project Overview

The AI Inbound Calling Agent is an intelligent, Urdu-speaking virtual assistant designed to automate inbound customer support for the University of Sargodha (UOS). It integrates Automatic Speech Recognition (ASR), Natural Language Understanding (NLU), and Text-to-Speech (TTS) technologies to manage real-time calls, understand natural language queries, and deliver accurate, context-aware responses in both Urdu, English and hybrid of both languages.

1.3 Scope

The system's included functionalities will be:

- i. Automatically answers inbound calls and interacts with callers in real time.
- ii. Uses speech recognition and Natural Language Understanding (NLU) to identify intent and provide accurate responses.
- iii. Supports bilingual communication in both English and Urdu and hybrid of two.
- iv. Retrieves essential information from the university's database, including admission schedules, departmental contacts, office timings, and event details and others.
- v. Allows seamless call transfer to a human operator for complex queries.
- vi. Provides an analytics dashboard to monitor call volume, response accuracy, and performance based on system logs and user feedback.
- vii. Includes basic urgency detection to improve response quality and user experience.

The system's excluded functionalities will be:

- I. Outbound or promotional calling.
- II. Video or chat-based communication.
- III. Integration with social media or non-telephony communication platforms.
- IV. External Support for non-verbal communication modes (e.g., emails, or text chat).

2. Design Considerations

The design of the AI Inbound Calling Agent for university admissions must account for diverse caller backgrounds, heavy call traffic during admission cycles, and Pakistan's inconsistent telecommunication conditions. Since users may speak in Urdu, English, or a code-switched mix, the system requires accurate, low-latency ASR and reliable intent detection under noise and variable speech patterns. It must operate stably despite network fluctuations, ensure secure real-time integration with university databases, and comply with relevant data protection laws. Clear fallback mechanisms and escalation to human operators

are necessary for complex or sensitive queries. These considerations directly shape the system's architecture, model selection, telephony pipeline, and error-handling strategies to deliver a robust and accessible admission support solution.

2.1 Assumptions and Dependencies

2.1.1 Assumptions

1. Stable Telephony and Network Connectivity

VoIP/PSTN gateways are expected to provide stable audio streams with minimal jitter, and continuous internet connectivity is assumed for real-time ASR, NLU, and TTS.

2. Cloud ASR and TTS Services Remain Available and Reliable

External speech services (e.g., OpenAI/Google) are assumed to remain available and perform consistently for Urdu, English, and mixed-language queries.

3. Callers Frequently Use Bilingual Code-Switching

Callers are expected to frequently switch between Urdu and English, influencing ASR, NLU, and TTS configuration..

4. Structured & Updated University Data

The Neo4j knowledge graph is assumed to receive regularly updated, well-structured datasets for admissions, departments, and schedules.

5. System Will Operate in a Cloud or Hybrid Deployment

The system is assumed to run in a cloud or hybrid setup capable of handling ASR/TTS workloads and concurrent call sessions.

6. Session-Based Conversation Handling

Each call is assumed to maintain a separate session with temporary context for multi-turn dialogue without long-term memory.

2.1.2 Dependencies

1. ASR, NLU, and TTS Engines

System performance depends on cloud-based AI components. An API failure or degradation directly impacts the call flow and user experience.

2. Telephony Provider (VoIP/PSTN)

The system depends on SIP trunks or telephony gateways for receiving calls, routing sessions, and streaming audio.

3. Backend Services and Flask API

All modules communicate through the central orchestrator. The entire pipeline relies on Flask for routing, session management, and middleware operations.

4. **Message Queue (RabbitMQ/Kafka)**
Reliable streaming of audio chunks and non-blocking ASR/NLU/TTS pipelines depends on a stable message queuing service.
5. **Neo4j/GraphRAG Knowledge Base**
Contextual and accurate answers depend on the proper functioning, indexing, and updating of the knowledge graph.
6. **System Logs and Storage Services**
Logging, analytics, and call summaries rely on secure storage services with suitable retention policies.

2.2 Risks and Volatile Areas

This subsection identifies the major sources of uncertainty which may affect the system's design or long-term maintainability.

2.2.1 Technology Risks

1. **Variations in Urdu/English Speech Patterns**
ASR accuracy may drop due to regional accents, background noise, or rapid code-switching. This may introduce misinterpretations or incomplete responses.
2. **Cloud API Changes (Pricing or Rate Limits)**
AI service providers may change pricing, quotas, or model availability, which could influence cost and architectural choices.
3. **Telephony Integration Issues**
Differences in SIP protocols, codecs, or network configurations may require design adjustments in the call-handling layer.

2.2.2 Requirements and Data Volatility

1. **Rapidly Changing University Information**
Admission dates, fee structures, and department updates frequently change. Designing for regular updates is necessary to avoid outdated responses.
2. **Expanding Query Categories**
Over time, more departments may need to be added, increasing the complexity of intent classification and knowledge graph growth.
3. **Operational Policies May Evolve**
Changes such as new call escalation rules or call-duration limits can affect the design of call flow and routing logic.

2.2.3 Security and Privacy Risks

1. **Handling Caller Information**

Even though the system avoids storing sensitive data, logs still pose risks if not encrypted or anonymized.

2. **Compliance Requirements**

Regulations (e.g., GDPR/PDPL) may evolve, requiring changes to data handling, retention, and anonymization strategies.

2.2.4 Performance Risks

1. **High Call Volume Peaks**

During peak periods (admissions), concurrent call demand may exceed model or server capacity.

2. **Pipeline Latency**

ASR → NLU → TTS may introduce noticeable delays if models or network conditions degrade.

3. **Knowledge Graph Query Delays**

Slow or inefficient graph queries can cause response lag, especially under load.

2.3 Constraints Influencing the Design

1. **Real-Time Responsiveness**

The system must deliver responses within approximately 2 seconds, which limits the use of heavy models or complex inference pipelines.

2. **Inbound Voice-Only Constraint**

The system is restricted to voice-based communication. No chat, email, AI chat bot, or outreach module is included in the design.

3. **Compliance and Legal Constraints**

The system must follow GDPR/PDPL guidelines, avoiding storage of personal identifiers or raw audio where unnecessary.

4. **Hardware and Bandwidth Limitations**

Real-time ASR/TTS performance is sensitive to CPU, memory, and especially network bandwidth.

5. **Language Constraints**

The design must handle Urdu-English mixed speech without requiring separate pipelines.

6. **No Proprietary Telephony Hardware**

The solution must be compatible with generic VoIP systems, limiting the use of specialized hardware optimizations.

3. System Architecture

3.1 System Level Architecture

At the highest level, the AI Inbound Calling Agent is divided into three major layers:

A. Telephony and Audio Interface Layer

Handles inbound call reception, audio streaming, SIP/VoIP communication, session setup, and initial routing.

B. AI Processing Layer (Core Intelligence)

Processes spoken input and generates responses. This includes ASR, NLU, intent classification, Neo4j/GraphRAG retrieval, response generation, and TTS.

C. Backend Services & Management Layer

Provides APIs, logging, analytics, error handling, configuration, and admin dashboard functions

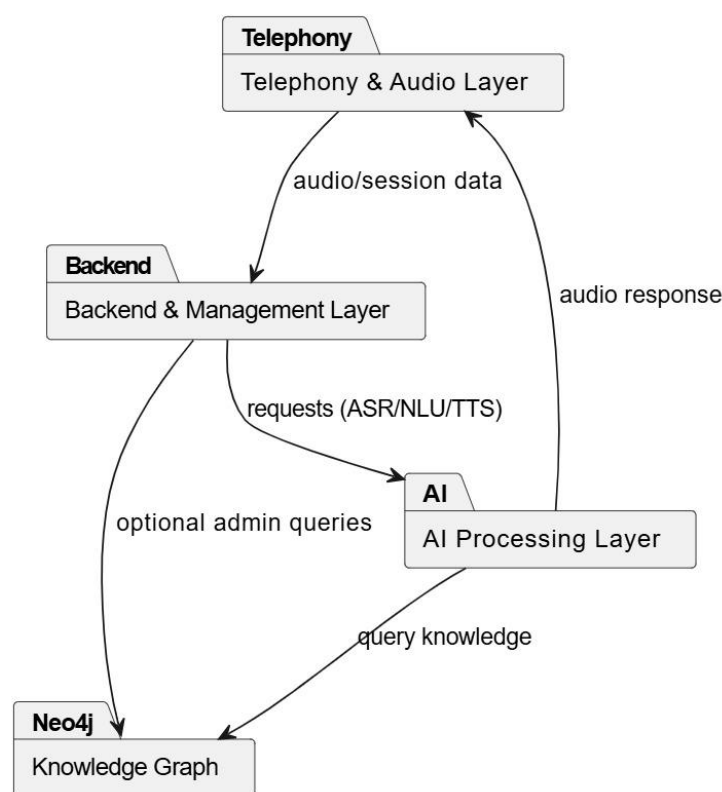


Figure 3.1: System Architecture Diagram

3.1.1 System Decomposition into Elements

System Element	Role
Telephony Gateway (VoIP/PSTN)	Receives inbound calls; streams audio to backend
Audio Session Manager	Manages per-caller interactions, buffering, session state
ASR Module	Converts caller speech (Urdu/English/code-switching) to text
NLU & Intent Engine	Identifies user intent, entities, and query type
Knowledge Retrieval (GraphRAG + Neo4j)	Fetches contextual, structured UOS information
Response Generator	Formulates natural language reply
TTS Module	Converts textual response into natural Urdu/English speech
Flask Backend / API Gateway	Orchestrates all modules and handles communication
Logs & Monitoring	Stores call summaries, timestamps, error reports
Admin Dashboard	Provides analytics to university staff

3.1.2 Relationships Between the Elements

1. Telephony receives the call → sends audio stream to Backend
2. Backend forwards audio chunks → ASR
3. ASR text → NLU
4. NLU → Intent classification
5. Intent → GraphRAG/Neo4j (only if data retrieval required)
6. Retrieved info → Response generator
7. Response → TTS → Audio output
8. Audio → Sent back to caller through Telephony Gateway
9. The flow is strictly session-based to maintain conversation continuity.

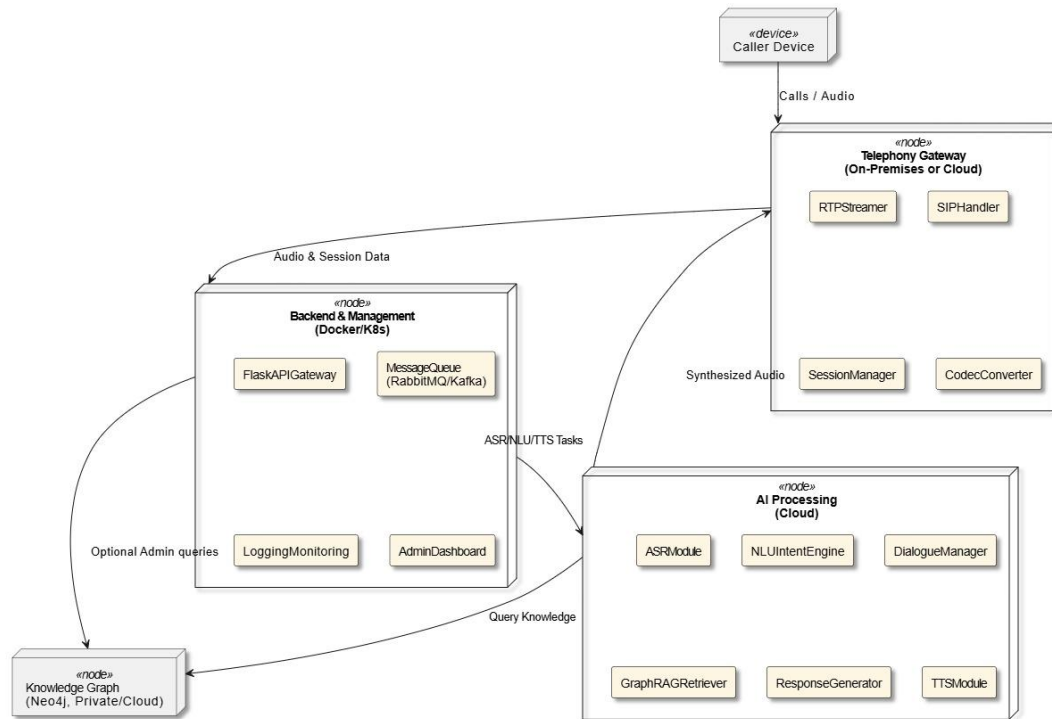


Figure 3.1.2: Deployment diagram

3.1.3 Interfaces to External Systems

External System	Interaction
VoIP/PSTN Telephony Gateway	Audio in/out, SIP signaling
OpenAI/Cloud ASR & TTS	Speech recognition & synthesis APIs
University Database / Neo4j	Graph-based information retrieval
Admin Dashboard (Web)	Call analytics, logs, monitoring

3.1.4 Major Physical Design / Deployment Considerations

1. Telephony gateway may run on-premises or cloud.
2. AI processing will run in cloud for lower latency and stable compute.
3. Knowledge graph (Neo4j) may be hosted on private server (UOS) or cloud.
4. Backend (Flask) runs in a containerized environment (Docker/K8s) for scalability.
5. Message queue (RabbitMQ/Kafka) facilitates parallel ASR/NLU/TTS pipelines.

3.1.5 Global Design Strategies

1. Error Handling:

- Retry logic for dropped ASR/TTS API calls.
- Fail gracefully (e.g., “Sorry, please repeat that.”).
- Default fallback responses for unknown intents.

2. Security:

- All communication over TLS/SRTP.
- Logs anonymized; no sensitive caller data stored.

3. Maintainability:

- Highly modular architecture allows replacing ASR/TTS engines.
- GraphRAG layer allows incremental knowledge updates without retraining models.

3.2 Sub-System / Component / Module Level Architecture.

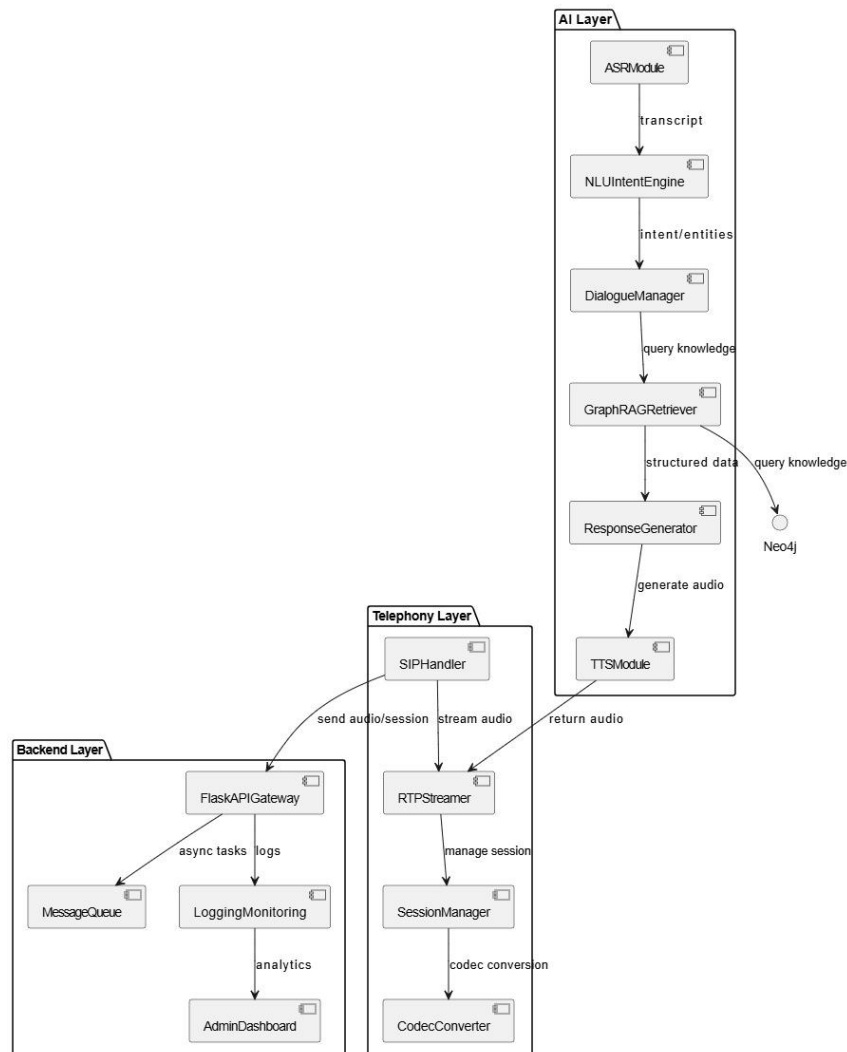


Figure 3.2: Component diagram

3.3 Sub-Component / Sub-Module Level Architecture (1...n)

3.3.1 ASR Sub-Module Architecture

Sub-components:

- Audio Chunk Handler
- Pre-processing (noise reduction, silence trim)
- ASR API Connector
- ASR Result Normalizer
- Error & Retry Handler

Interactions:

- Streams chunks → sends to ASR API
- Receives partial/transcript → normalizes → sends to NLU

3.3.2 NLU Sub-Module Architecture

Sub-components:

- Tokenizer
- Intent Classifier
- Entity Extractor
- Context Manager
- Fallback Detector

Interactions:

- Receives text → identifies intent → routes to Dialogue Manager
- Handles ambiguous utterances
- Maintains per-call context (short-term memory)

3.3.3 Knowledge Retrieval (GraphRAG) Sub-Modules

Sub-components:

- Query Builder

- Graph Traversal Engine
- Relevance Ranking
- Data Formatter

Interactions:

- Builds query based on intent/entities
- Searches Neo4j
- Returns structured information to Response Generator

3.3.4 TTS Sub-Module Architecture

Sub-components:

- Text Normalization
- Language Decision (Urdu/English mix)
- TTS API Connector
- Audio Chunk Generator
- Audio Stream Router

3.3.5 Sequence Diagram

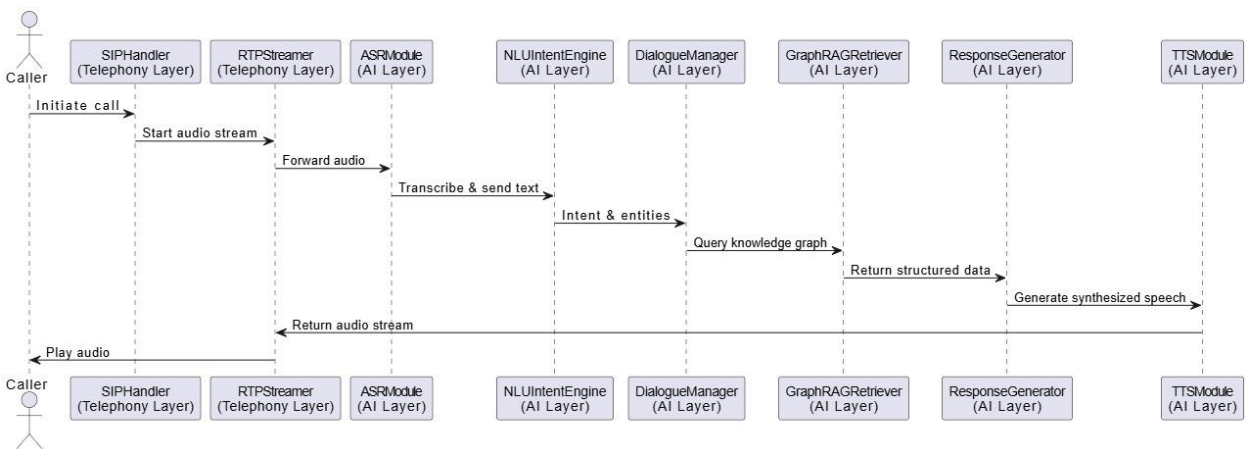


Figure 3.3.5: Sequence diagram

3.3.6 Activity Diagram

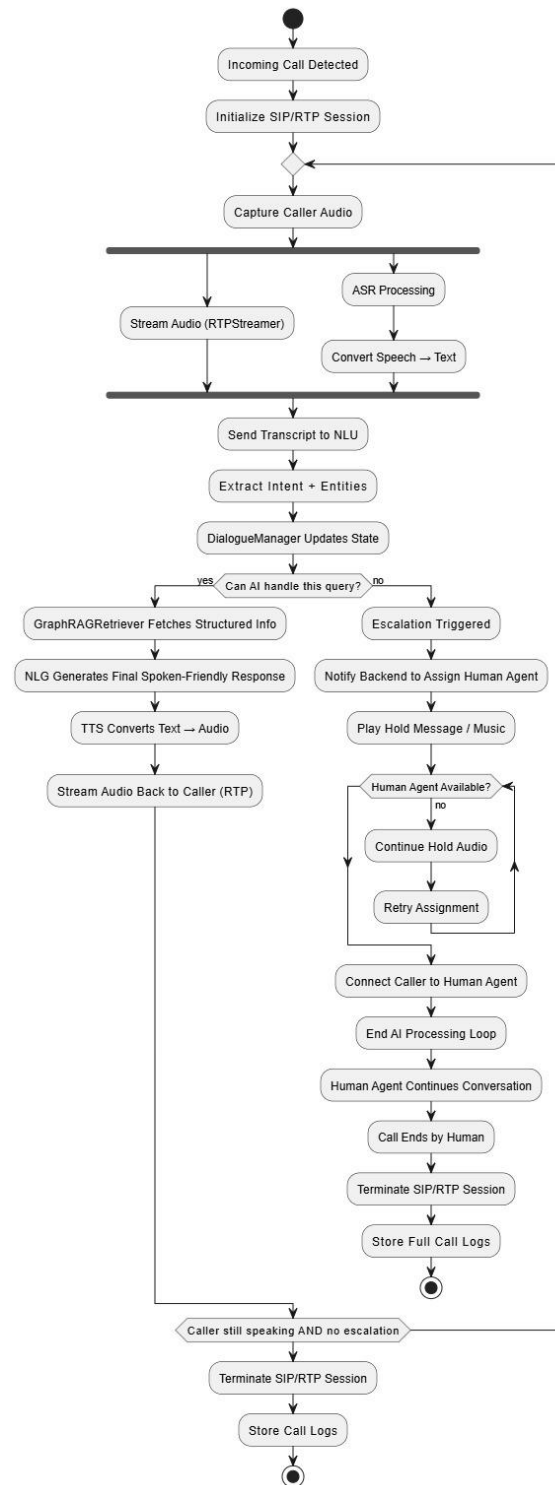


Figure 3.3.5: Sequence diagram

4. Design Strategies

4.1 Strategy 1: Modularity

Allows replacing ASR/TTS/knowledge components without redesigning full system.

4.2 Strategy 2: Scalability

Cloud-based processing enables horizontal scaling during peak admission periods.

4.3 Strategy 3: Fault Tolerance

Retry logic, fallback prompts, queue-based processing improve robustness.

4.4 Strategy 4: Security by Design

TLS/SRTP, anonymized logs, role-based dashboard access.

4.5 Strategy 5: Maintainability

Knowledge graph updates without retraining models.

5. Detailed System Design

5.1 State Transition Diagram

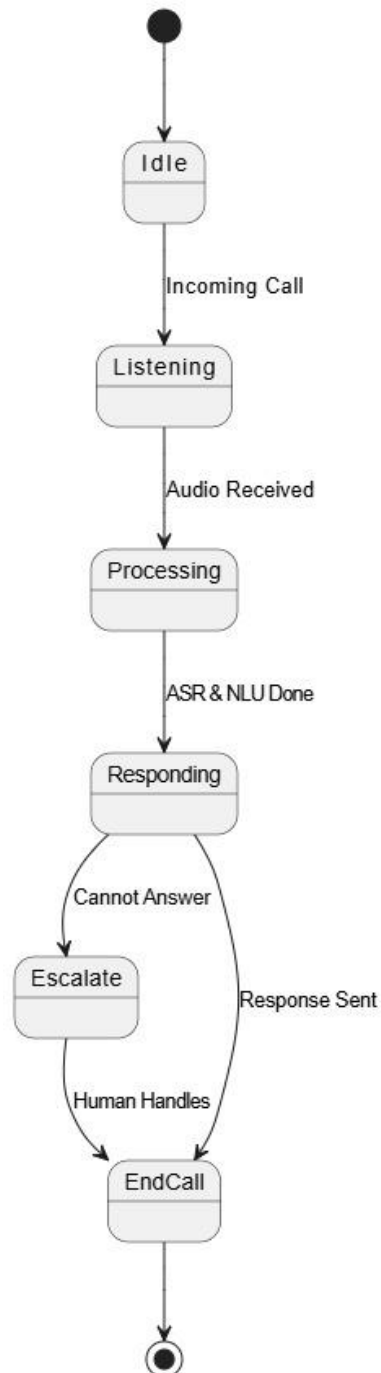


Figure 5.1: State Transition Diagram

5.2 Logical Data Model

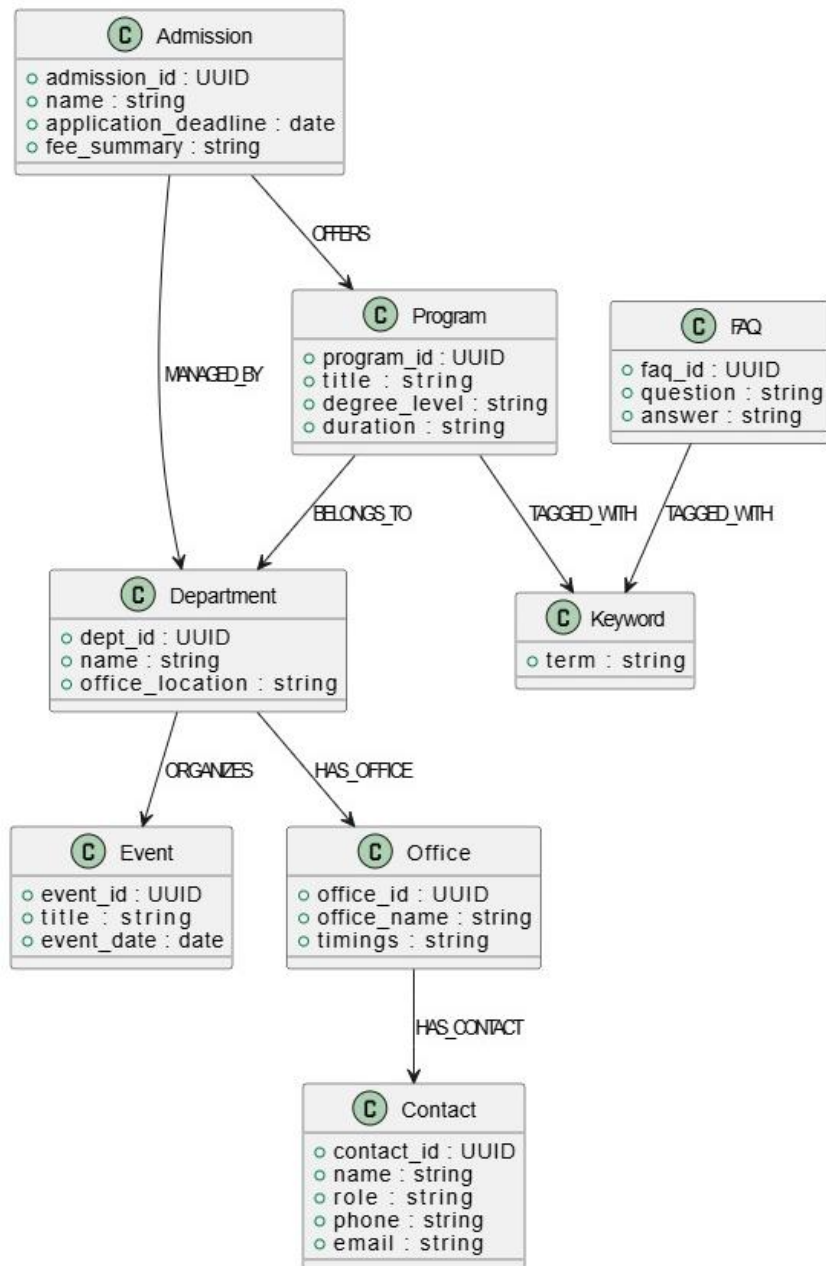


Figure 5.2: Logical data model

5.3 Physical Data Model

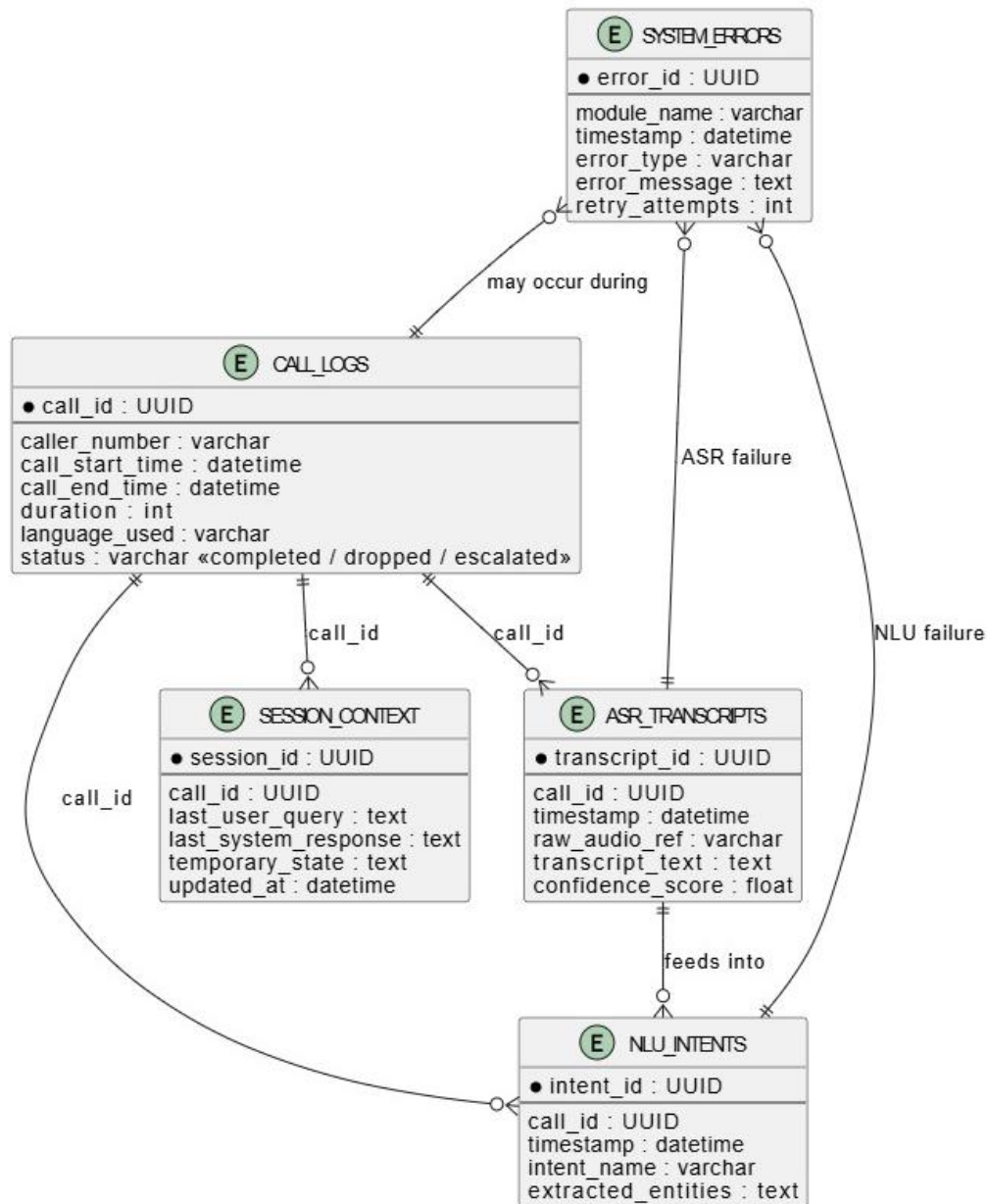


Figure 5.3: Physical data model

6. References

Ref. No.	Document Title	Date of Release/ Publication	Document Source
PGBH01-2025-Proposal	Project Proposal	Sept 23, 2025	https://github.com/AI-INBOUND-CALLING-AGENT/Proposal.pdf
PGBH01-2025-FS	Functional Specification	Oct 11 , 2025	https://github.com/AI-Inbound Calling Agent/SRS.pdf