

Module Guide for Software Engineering

Team 13, Speech Buddies

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1 Revision History

| Date | Version | Notes |
|--------------|---------|---------------------------------------|
| Nov 11, 2025 | 1.0 | Added modules and Traceability Matrix |
| Nov 12, 2025 | 1.1 | Added Modules M6-M11 |
| Nov 12, 2025 | 1.2 | Added Modules M18-M22 |
| Nov 26, 2025 | 1.3 | Added Modules M1-M6 |
| Jan 10, 2026 | 1.4 | Implemented TA Feedback for M7-M11 |

2 Reference Material

This section records information for easy reference.

2.1 Abbreviations and Acronyms

| symbol | description |
|----------------------|-------------------------------------|
| AC | Anticipated Change |
| DAG | Directed Acyclic Graph |
| M | Module |
| MG | Module Guide |
| OS | Operating System |
| R | Requirement |
| SC | Scientific Computing |
| SRS | Software Requirements Specification |
| Software Engineering | Explanation of program name |
| UC | Unlikely Change |
| FR | Functional Requirement |
| LF | Look and Feel |
| PF | Performance |
| OER | Operational & Environmental |
| MS | Maintainability & Support |
| SEC | Security |
| CUL | Cultural |
| CPL | Compliance |

Contents

| | | |
|-----------|---|-----------|
| 1 | Revision History | 1 |
| 2 | Reference Material | 2 |
| 2.1 | Abbreviations and Acronyms | 2 |
| 3 | Introduction | 1 |
| 4 | Anticipated and Unlikely Changes | 2 |
| 4.1 | Anticipated Changes | 2 |
| 4.2 | Unlikely Changes | 3 |
| 5 | Module Hierarchy | 4 |
| 6 | Connection Between Requirements and Design | 5 |
| 7 | Module Decomposition | 6 |
| 8 | Traceability Matrix | 17 |
| 9 | Use Hierarchy Between Modules | 19 |
| 10 | User Interfaces | 20 |
| 11 | Design of Communication Protocols | 20 |
| 12 | Timeline | 20 |
| 12.1 | Development Phases | 20 |
| 12.2 | Task Responsibilities | 21 |

List of Tables

| | | |
|----|--|----|
| 1 | Module Hierarchy | 5 |
| 2 | Trace Between Functional Requirements and Modules | 17 |
| 3 | Trace Between Look & Feel Requirements and Modules | 17 |
| 4 | Trace Between Usability & Humanity Requirements and Modules | 17 |
| 5 | Trace Between Performance Requirements and Modules | 18 |
| 6 | Trace Between Operational & Environmental Requirements and Modules | 18 |
| 7 | Trace Between Maintainability & Support Requirements and Modules | 18 |
| 8 | Trace Between Security Requirements and Modules | 19 |
| 9 | Trace Between Cultural Requirements and Modules | 19 |
| 10 | Trace Between Compliance Requirements and Modules | 19 |

List of Figures

| | | |
|---|---------------------------------------|----|
| 1 | Use hierarchy among modules | 20 |
|---|---------------------------------------|----|

3 Introduction

Decomposing a system into modules is a commonly accepted approach to developing software. A module is a work assignment for a programmer or programming team (Parnas et al., 1984). For VoiceBridge, we adopt this decomposition based fundamentally on Parnas’s principle of information hiding (Parnas, 1972). This principle supports design for change, because the “secrets” that each module hides represent likely future changes. This approach supports design for change, a critical concern in assistive technologies where adaptation to evolving user needs and cutting-edge speech recognition improvements frequently occur, especially in early development phases.

Our design follows the rules layed out by Parnas et al. (1984), as follows:

- System details that are likely to change independently should be the secrets of separate modules.
- Each data structure is implemented in only one module.
- Any other program that requires information stored in a module’s data structures must obtain it by calling access programs belonging to that module.

After completing the first stage of the design, the Software Requirements Specification (SRS), the Module Guide (MG) is developed (Parnas et al., 1984). The MG specifies the modular structure of the system and is intended to allow both designers and maintainers to easily identify the parts of the software. The potential readers of this document are as follows:

- New project members: This document can be a guide for a new project member to easily understand the overall structure and quickly find the relevant modules they are searching for.
- Maintainers: The hierarchical structure of the module guide improves the maintainers’ understanding when they need to make changes to the system. It is important for a maintainer to update the relevant sections of the document after changes have been made.
- Designers: Once the module guide has been written, it can be used to check for consistency, feasibility, and flexibility. Designers can verify the system in various ways, such as consistency among modules, feasibility of the decomposition, and flexibility of the design.

The rest of the document is organized as follows. Section 4 lists the anticipated and unlikely changes of the software requirements. Section 5 summarizes the module decomposition that was constructed according to the likely changes. Section ?? specifies the connections between the software requirements and the modules. Section ?? gives a detailed description of the modules. Section 8 includes two traceability matrices. One checks the completeness

of the design against the requirements provided in the SRS. The other shows the relation between anticipated changes and the modules. Section 9 describes the use relation between modules.

4 Anticipated and Unlikely Changes

This section lists possible changes to the system. According to the likeliness of the change, the possible changes are classified into two categories. Anticipated changes are listed in Section 4.1, and unlikely changes are listed in Section 4.2.

4.1 Anticipated Changes

Anticipated changes are the source of the information that is to be hidden inside the modules. Ideally, changing one of the anticipated changes will only require changing the one module that hides the associated decision. The approach adapted here is called design for change.

AC1: Hardware platform and input devices.

Advancements in microphone technology, such as arrays or new form factors, alongside evolving processing hardware, may improve audio quality, reduce costs, and enable integration with wearable devices. These changes influence audio acquisition and pre-processing modules.

AC2: Speech-to-text engine and language support.

The system might expand to support additional languages and dialects beyond English requiring adaptations in ASR models and intent interpretation logic. Continuous improvements in speech recognition accuracy and noise filtering will also necessitate regular updates.

AC3: User profile and personalization management.

Personalization features may evolve to accommodate changing user speech patterns and preferences, demanding updates in model fine-tuning, adaptive prompting based on confidence, and profile management strategies.

AC4: Command mapping and browser automation protocols.

Updates may introduce new commands, integrate with emerging browser APIs, or improve error detection and recovery in command execution modules.

AC5: User interface and accessibility compliance.

Responsive adjustments to UI designs and accessibility layers will be required to stay compliant with evolving WCAG guidelines and to address user feedback for improved usability.

AC6: Error handling and recovery policies.

Classification schemes, messaging protocols, retry/backoff strategies, and compensation mechanisms may be enhanced to increase robustness and user experience quality.

AC7: Session lifecycle and interaction flow.

Changes may extend session duration limits, improve state persistence, and better handle asynchronous or interrupted user interactions.

AC8: Data privacy, audit logging, and security.

Adaptations will be necessary to comply with evolving data privacy laws and security best practices, affecting encryption, audit trail formats, and consent mechanisms.

AC9: Personalization and prompting enhancements.

Enhancements aiming at more context-aware and confidence-driven user assistance will continually refine prompting and instruction modules.

4.2 Unlikely Changes

The module design should be as general as possible. However, a general system is more complex. Sometimes this complexity is not necessary. Fixing some design decisions at the system architecture stage can simplify the software design. If these decision should later need to be changed, then many parts of the design will potentially need to be modified. Hence, it is not intended that these decisions will be changed.

UC1: Switching to specialized or high-end microphones and audio hardware.

VoiceBridge targets consumer-grade devices using standard microphones, ensuring affordability and accessibility. Moving to uncommon or costly hardware is outside the project scope and is therefore unlikely.

UC2: Offloading speech processing or command execution to external or cloud systems.

To protect user privacy and maintain responsiveness, VoiceBridge performs all key processing locally. Changing this would require major architecture redesign and is not planned.

UC3: Fundamental changes to the speech recognition approach.

The system uses specialized ASR models tuned for speech impairments based on proven models. Major shifts in ASR methodology would be disruptive and are therefore improbable.

UC4: Complete redesign of command mapping and browser control modules.

These modules are tightly coupled with browser APIs and OS functions for stability and usability. Major rewrites would cause extensive system impact and are unlikely.

UC5: Abandoning modular design for a monolithic or radically different architecture.

Modularity was chosen for maintainability and scalability. Changing to a less modular approach would increase complexity and reduce flexibility.

5 Module Hierarchy

This section provides an overview of the module design. The system is organized into architectural layers, each containing modules that encapsulate specific responsibilities. Table 1 presents the hierarchy of modules by their layers, including their primary purposes and responsibilities. The modules listed below, which are leaves in the hierarchy tree, are the modules that will be implemented.

- M1:** User Interface Module
- M2:** Accessibility Layer
- M3:** Feedback Display Module
- M4:** Speech-to-Text Engine
- M5:** Intent Interpreter
- M6:** Command Mapping Module
- M7:** Command Execution Layer
- M8:** Error Feedback
- M9:** Browser Controller
- M10:** Session Manager
- M11:** Error Handling & Recovery Module
- M12:** Data Management Layer
- M13:** User Profile Manager
- M14:** Audit Logger
- M15:** Credential Manager
- M16:** Encryption Manager
- M17:** Out-of-Scope Handler
- M18:** Microphone Manager
- M19:** VAD Noise Filter
- M20:** Prompting Module
- M21:** Model Tuner
- M22:** Instruction Registry

6 Connection Between Requirements and Design

The design of the system is intended to satisfy the requirements developed in the (SRS). In this stage, the system is decomposed into modules. The connection between requirements and modules is listed in Table 1.

| Architectural Layer | Included Modules | Purpose / Responsibilities |
|---------------------------------------|---|--|
| Presentation Layer | User Interface Module Accessibility Layer Feedback Display Module | Manages direct user interaction and feedback presentation. Displays transcribed text, confirmations, feedback messages, and status indicators. Ensures compliance with WCAG accessibility standards including contrast, font, and color. |
| Application (Processing) Layer | Speech-to-Text Engine Intent Interpreter Command Mapping Module Command Execution Layer Error Feedback Module | Performs speech recognition and intent processing. Converts speech audio to text, interprets user intent, maps intent to browser or OS commands, executes commands, and handles error feedback. |
| Control (Orchestration) Layer | Browser Controller Session Manager Error Handling and Recovery Module | Coordinates and manages flow between modules. Tracks session states such as capture, transcribe, confirm, and execute. Manages events, exceptions, retries, and cancellations to ensure smooth operation. |
| Data Management Layer | Data Storage Manager User Profile Manager Audit Logger | Maintains persistent data and user personalization. Stores user speech samples, preferences, command mappings, transcripts, and logs. Supports diagnostics and evaluation. |
| Security Layer | Credential Manager Encryption Manager Out-of-Scope Handler | Manages authentication, encryption, and system boundaries. Ensures secure integration with external APIs and operating system interfaces. Handles login confirmations. |
| Input Processing Layer | Microphone Manager VAD and Noise Filter | Controls microphone hardware and audio capture. Filters noise to improve voice input quality. |
| Personalization Layer | Prompting Module Model Tuner Instruction Registry | Provides user prompting, model fine-tuning, and instruction management. Supports optional personalization based on confidence scores and usage history. |

Table 1: Module Hierarchy

7 Module Decomposition

Presentation Layer Modules

M1: User Interface Module

Secrets:

- Representation of UI state, layout, and visible components
- Mapping of raw browser events into UiEvents
- Management of keyboard and screen-reader focus

Services:

- Initialize and render UI
- Receive and normalize input events into UiEvents
- Route feedback items
- Update keyboard and screen-reader focus

Implemented By: UserInterface module using the browser rendering engine and DOM/event APIs.

M2: Accessibility Layer

Secrets:

- Encoding of accessibility configuration (AccessConfig)
- ARIA attribute mappings
- Validation rules for UI elements against WCAG standards

Services:

- Apply accessibility options
- Announce messages
- Check UI elements and report problems using ValidationReports

Implemented By: AccessibilityLayer module operating on UI elements exposed by UserInterface.

M3: Feedback Display Module

Secrets:

- Internal representation of FeedbackItems keyed by UUID
- Policies for creation, clearance, and recovery options of feedback messages

Services:

- Attach to parent UI
- Show messages of given types
- Clear messages
- Create recovery options for feedback items

Implemented By: FeedbackDisplay module rendering via UserInterface and coordinating with AccessibilityLayer.

Application (Processing) Modules

M4: Speech-to-Text Engine

Secrets:

- Configuration (AsrConfig) and internal processing details of the speech-to-text engine
- Methods for converting audio input into accurate text transcripts

Services:

- Initialize engine
- Process audio to produce transcripts with confidence metadata
- Reset internal state

Implemented By: SpeechToTextEngine module wrapping acoustic and language models.

M5: Intent Interpreter

Secrets:

- Recognition of user intentions using stored intent templates
- Management of conversation context
- Extraction of key details (slots) from user speech

Services:

- Initialize the interpreter
- Convert speech transcripts into structured intentions
- Extract details and confidence levels
- Reset interpreter context

Implemented By: IntentInterpreter module using registered intent templates and dialog state management.

M6: Command Mapping Module

Secrets:

- Command registry structure
- User preferences and policy application for mapping

Services:

- Initialize mapping
- Map Intents to validated Commands
- Validate commands against guardrails
- Reset internal state

Implemented By: CommandMapping module using command registry, preferences, and policy configurations.

Application (Processing) Modules

M7: Command Execution Layer

Secrets:

- Command validation and mapping to backend requests
- Dispatching, tracking, cancellation, and timeout logic
- Internal queueing and audit formats

Services:

- Execute, cancel, and provide status for commands
- Translate commands to backend formats
- Provide rollback hooks

Implemented By: Core runtime (browser bridge + OS process APIs).

M8: Error Feedback

Secrets:

- Expected error types
- Message templates and localization hooks
- Mapping of internal/domain errors to user-facing message keys and recovery options
- Redaction rules for logs and UI

Services:

- Display error notifications
- Display recovery prompts with options
- Dismiss items
- Log structured error events
- Normalize and map errors to UI messages and recovery actions

Implemented By: UI Notification Layer and Shared Error Handling Module (M11).

Control (Orchestration) Modules

M9: BrowserController

Secrets:

- Transport protocol to the browser controller
- Timeout wrappers and normalization of responses
- Session plumbing

Services:

- Send request
- Get status
- Cancel operations
- Open and close controller sessions

Implemented By: Automation bridge client.

M10: Session Manager

Secrets:

- Session lifecycle rules
- Storage schema
- TTL and expiry handling

Services:

- Start and stop sessions
- Get session state
- Attach commands
- Set state

Implemented By: In-memory cache + persistent store.

M11: Error Handling & Recovery Module

Secrets:

- Error classification policy
- Retry and backoff strategies
- Compensation catalog

Services:

- Handle error
- Retry and compensate
- Classify errors
- Record events

Implemented By: Orchestration runtime with policy store.

M12: Storage Management Module

Secrets:

- Database connection credentials
- Cloud API tokens
- Encryption keys

Services:

- `DataStorageService`: Stores and retrieves transcripts, user data, and configuration files.
- `BackupService`: Performs scheduled or manual backups to secure cloud storage.
- `DataRetrievalService`: Provides indexed access to stored files for authorized modules.
- `DataRetentionService`: Enforces deletion and retention rules based on time or policy.

Implemented By: `DataStorageManager`.

M13: User Profile Management Module

Secrets:

- User tokens and refresh keys
- Profile encryption keys
- Hashed user identifiers

Services:

- ProfileCreationService: Initializes new user profiles with unique IDs.
- PreferenceService: Saves and retrieves user preferences and personalization data.
- ConsentManagementService: Records and verifies consent for data collection and personalization.

Implemented By: UserProfileManagerImpl.

M14: Audit Logging Module

Secrets:

- Log signing key
- Audit database token
- Log encryption key

Services:

- ActivityLogService: Logs system and user activities for traceability.
- LogQueryService: Provides authorized access to query and review logs.
- AnomalyDetectionService: Detects suspicious activity and security anomalies.

Implemented By: AuditLoggerImpl.

M15: Credential Management Module

Secrets:

- Vault master key
- Token signing keypair
- OAuth client secrets

Services:

- AuthenticationService: Validates user credentials during login.
- SessionTokenService: Issues and validates secure access tokens (JWT/OAuth).
- PasswordVaultService: Stores and retrieves hashed passwords securely.

Implemented By: CredentialManagerImpl.

M16: Encryption Management Module

Secrets:

- Private encryption keypair
- TLS certificates for secure communication
- Key rotation schedule metadata

Services:

- DataEncryptionService: Encrypts data at rest and in transit.
- KeyManagementService: Generates, rotates, and revokes cryptographic keys.
- AnonymizationService: Removes identifiable data prior to model training or storage.
- IntegrityVerificationService: Ensures stored or transmitted data has not been altered.

Implemented By: EncryptionManagerImpl.

M17: Out-of-Scope Handling Module

Secrets:

- Command whitelist/blacklist configuration
- Safety policy file checksum
- Secure incident reporting token

Services:

- `CommandValidationService`: Validates command scope and prevents unsafe actions.
- `UserSafetyService`: Provides safe fallback messages and cancel options.
- `RecoveryService`: Rolls back partially executed or invalid operations.
- `IncidentReportingService`: Reports anomalies and unsafe commands to the `AuditLogger`.

Implemented By: `OutOfScopeHandlerImpl`.

Input Processing Layer Modules

M18: Microphone Manager

Secrets:

- Device-level audio capture configuration and sampling parameters
- Buffering strategy and fallback device selection
- Normalization of raw audio before downstream processing

Services:

- Start and stop microphone stream
- Read audio frames
- Provide normalized PCM buffer
- Expose current device status and surface hardware errors

Implemented By: Browser audio APIs or OS audio interface.

M19: VAD Noise Filter

Secrets:

- Voice-activity-detection thresholds
- Noise-suppression heuristics and smoothing windows
- Adaptive gain rules

Services:

- Filter raw microphone frames
- Determine speech vs. silence
- Emit clean audio frames
- Send VAD events (start/stop speech)

Implemented By: DSP/VAD library.

Personalization Layer

M20: Prompting Module

Secrets:

- Prompt templates and personalization rules
- Condition-based variation (history, context)
- Confidence-based prompt selection logic

Services:

- Generate user prompts
- Provide clarifying follow-ups when intent confidence is low
- Produce culturally inclusive and accessibility-enabled copy

Implemented By: Application prompt engine.

M21: Model Tuner

Secrets:

- Adaptation strategy for user-specific speech patterns
- Tuning weights for model updates
- Online vs. offline update thresholds
- Embedding storage rules

Services:

- Update inference parameters based on user data
- Compute personalized embeddings
- Adjust thresholds for intent classification and STT confidence

Implemented By: ML runtime (Whisper fine-tuning layer or lightweight personalization pipeline).

M22: Instruction Registry

Secrets:

- Internal representation of user-custom commands
- Schema for mapping instructions to intents
- Safety constraints preventing unsafe or ambiguous command creation

Services:

- Store, update, and delete user instructions
- Resolve user-defined commands during intent parsing
- Validate new instructions
- Expose registry lookup API

Implemented By: Local or cloud command registry service.

8 Traceability Matrix

The traceability matrices show how each requirement is implemented by specific modules and how each anticipated change is isolated within a single module.

| Req. | Modules |
|-----------|-------------------|
| FR-1 10.1 | M18, M19, M4, M10 |
| FR-2 10.2 | M4, M19, M21, M12 |
| FR-3 10.3 | M1, M2, M3, M8 |
| FR-4 10.4 | M5, M6, M22 |
| FR-5 10.5 | M7, M9, M11, M8 |

Table 2: Trace Between Functional Requirements and Modules

| Req. | Modules |
|-----------|-----------------|
| LF-1 11.1 | M1, M2, M3, M8 |
| LF-2 11.2 | M1, M2, M20, M3 |

Table 3: Trace Between Look & Feel Requirements and Modules

| Req. | Modules |
|-----------|------------------|
| UH-1 12.1 | M1, M2, M3, M8 |
| UH-2 12.2 | M13, M12, M5, M6 |
| UH-3 12.3 | M1, M2, M20, M10 |
| UH-4 12.4 | M8, M3, M2, M20 |
| UH-5 12.5 | M2, M1, M3, M8 |

Table 4: Trace Between Usability & Humanity Requirements and Modules

| Req. | Modules |
|-------------|---------------------|
| PF-1 13.1 | M4, M5, M6, M7, M9 |
| PF-2 13.2 | M5, M6, M7, M8, M11 |
| PF-3 13.3 | M4, M19, M21, M5 |
| PF-4 13.4 | M11, M10, M8, M9 |
| PF-5 13.5 | M10, M12, M13 |
| PF-6 13.6 | M10, M12, M7, M9 |
| PF-7 13.7 | M12, M13, M14, M15 |

Table 5: Trace Between Performance Requirements and Modules

| Req. | Modules |
|-------------|-------------------------|
| OER-1 14.1 | M18, M19, M4, M11 |
| OER-2 14.2 | M1, M2, M9, M10 |
| OER-3 14.3 | M5, M6, M9, M22 |
| OER-4 14.4 | M12, M13, M14, M15, M10 |
| OER-5 14.5 | M10, M12, M14, M15 |

Table 6: Trace Between Operational & Environmental Requirements and Modules

| Req. | Modules |
|-------------|------------------------------|
| MS-1 15.1 | M10, M12, M13, M14, M15, M22 |
| MS-2 15.2 | M1, M2, M3, M8, M20 |
| MS-3 15.3 | M1, M2, M9, M10, M11 |

Table 7: Trace Between Maintainability & Support Requirements and Modules

| Req. | Modules |
|------------|-------------------------|
| SEC-1 16.1 | M15, M16, M13, M12, M10 |
| SEC-2 16.2 | M5, M6, M7, M8, M11 |
| SEC-3 16.3 | M12, M13, M14, M15, M16 |
| SEC-4 16.4 | M14, M12, M10, M15 |
| SEC-5 16.5 | M11, M8, M19, M7, M9 |

Table 8: Trace Between Security Requirements and Modules

| Req. | Modules |
|------------|---------------------|
| CUL-1 17.1 | M2, M3, M8, M20, M5 |

Table 9: Trace Between Cultural Requirements and Modules

| Req. | Modules |
|------------|-------------------------|
| CPL-1 18.1 | M12, M13, M14, M15, M16 |
| CPL-2 18.2 | M1, M2, M3, M8 |

Table 10: Trace Between Compliance Requirements and Modules

9 Use Hierarchy Between Modules

In this section, the uses hierarchy between modules is provided. Parnas (1978) said of two programs A and B that A *uses* B if correct execution of B may be necessary for A to complete the task described in its specification. That is, A *uses* B if there exist situations in which the correct functioning of A depends upon the availability of a correct implementation of B. Figure 1 illustrates the use relation between the modules. It can be seen that the graph is a directed acyclic graph (DAG). Each level of the hierarchy offers a testable and usable subset of the system, and modules in the higher level of the hierarchy are essentially simpler because they use modules from the lower levels.

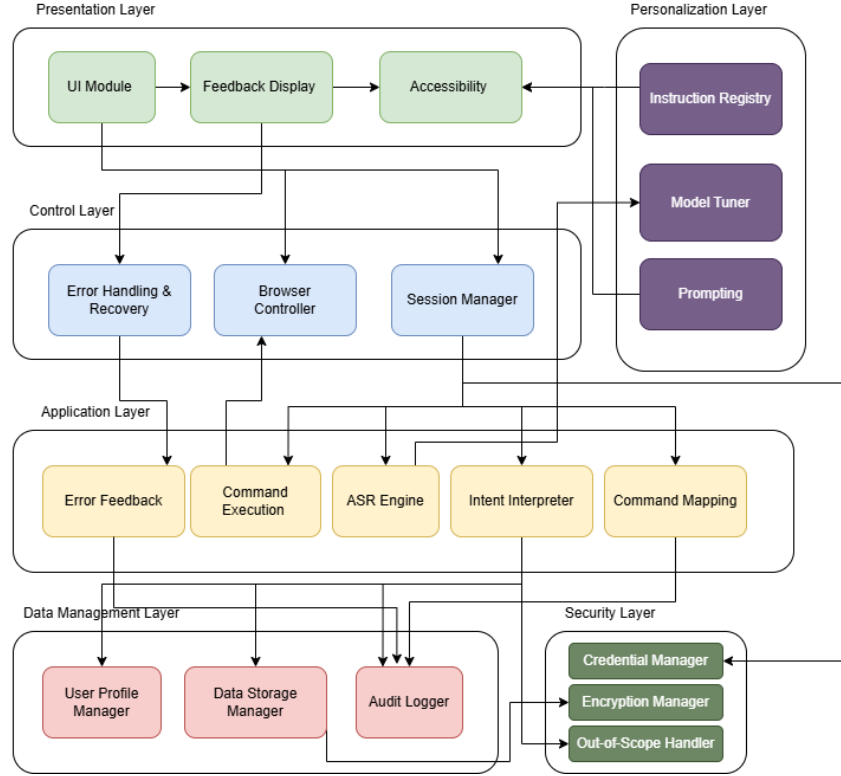


Figure 1: Use hierarchy among modules

10 User Interfaces

Will be defined in later design iterations.

11 Design of Communication Protocols

Not applicable at this time.

12 Timeline

The project is divided into phases with clear objectives, and all tasks are handled collaboratively — there is no single module ownership.

12.1 Development Phases

- **Foundational Development Phase (September – October 2025):** Core functionality such as speech-to-text, intent interpretation, and command mapping was developed collectively.

- **Integration and Testing Phase (November – December 2025):** The team works together to integrate modules, improve accessibility, and optimize performance.

12.2 Task Responsibilities

- Speech recognition and intent interpretation
- Command mapping and system integration
- User interface and accessibility
- Testing and performance optimization
- Documentation and support

All tasks are executed collaboratively, ensuring shared responsibility and smooth progress.

Note: The full timeline is outlined in Section 8 ("Project Decomposition and Scheduling") of the Development Plan document: <https://github.com/speech-buddies/VoiceBridge/blob/main/docs/DevelopmentPlan/DevelopmentPlan.pdf>

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