# Research Assistant Multi-Agent System

**Design using GAIA Methodology**

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April 22, 2025

## Problem Domain

### Background

Research literature review is crucial but presents significant challenges:

- Manual literature review is time-consuming and prone to overlooking relevant work
- PhD students need to quickly understand the state-of-the-art in new fields
- Research teams need to identify contradictory findings across multiple studies
- Processing the sheer volume of available research papers is overwhelming

### Importance

A comprehensive literature review is essential when:

- Writing academic papers and theses
- Starting to research already explored ideas
- Understanding a topic deeply to find research gaps
- Avoiding duplication of efforts in academic research

### Challenges

- **Information Overload:** The sheer volume of available research papers is overwhelming
- **Quality Assessment:** Determining the relevance and reliability of sources is difficult
- **Synthesis Complexity:** Connecting findings across diverse studies requires significant expertise
- **Time Constraints:** Thoroughly processing and extracting meaningful insights from each source is time-consuming

# 1 Multi-Agent System Design

## 1.1 Analysis Phase

### 1.1.1 Environmental Model

The environmental model represents the abstract and computational environment where our MAS will operate. The diagram below shows key resources that agents will interact with:

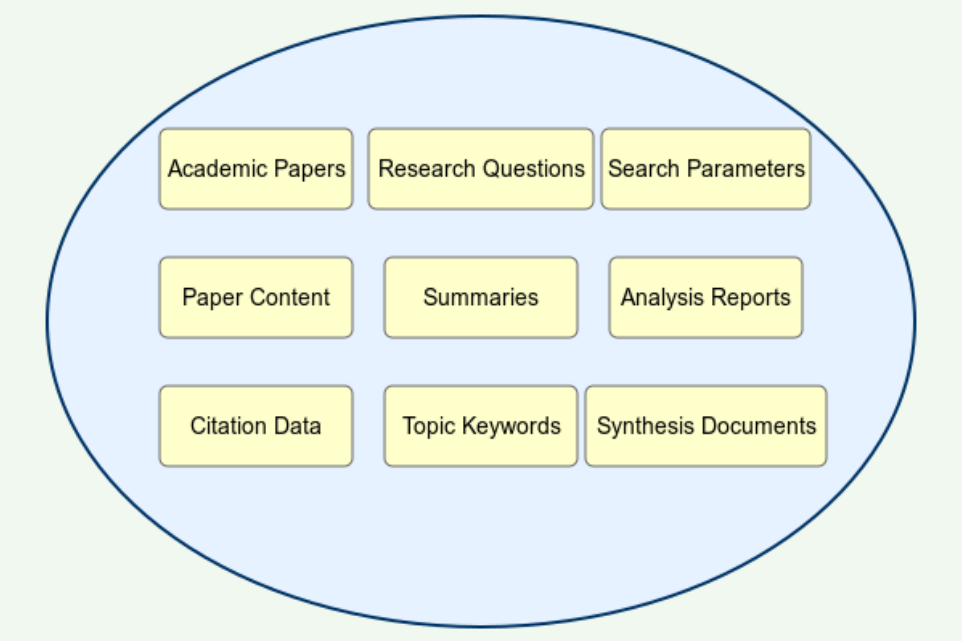


Figure 1: Environmental Model for Research Assistant MAS

### 1.1.2 Preliminary Role and Interaction Models

We have identified two key scenarios that our multi-agent system will address:

**Scenario 1: Comprehensive Literature Collection**

- **Challenge:** Researchers struggle to find all relevant papers across multiple databases and repositories.
- **Solution:** The Search Agent automatically queries multiple academic sources (Google Scholar, arXiv, PubMed), collecting comprehensive results beyond what a human could manually gather.

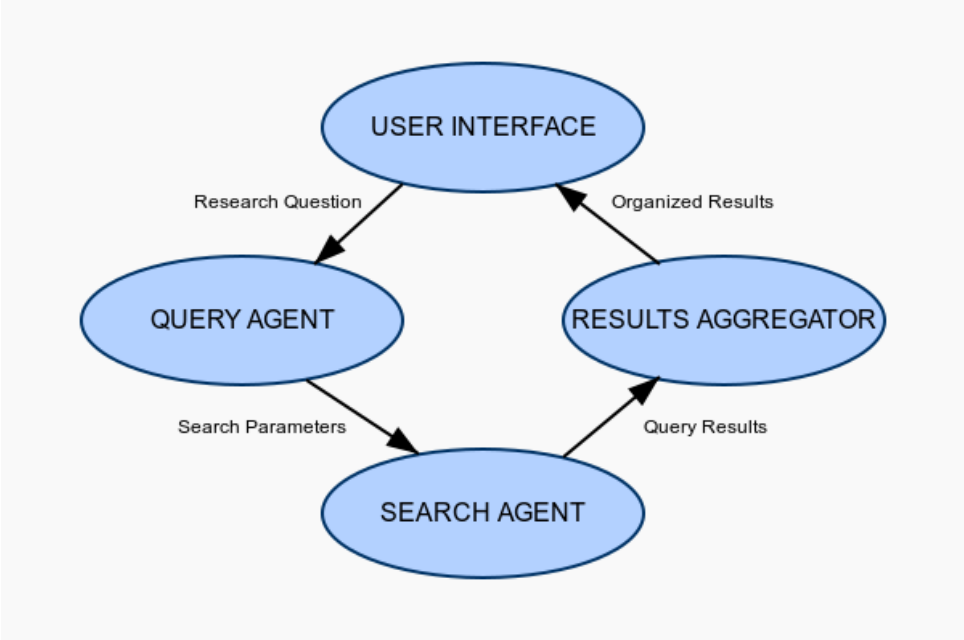


Figure 2: Preliminary Roles and Interactions for Scenario 1

**Scenario 2: Content Analysis and Synthesis**

- **Challenge:** Extracting key findings from dozens of papers is time-consuming and prone to oversight.
- **Solution:** The Analysis Agent reads papers, extracting methodologies and findings, while the Synthesis Agent connects related concepts across papers, identifying research gaps.

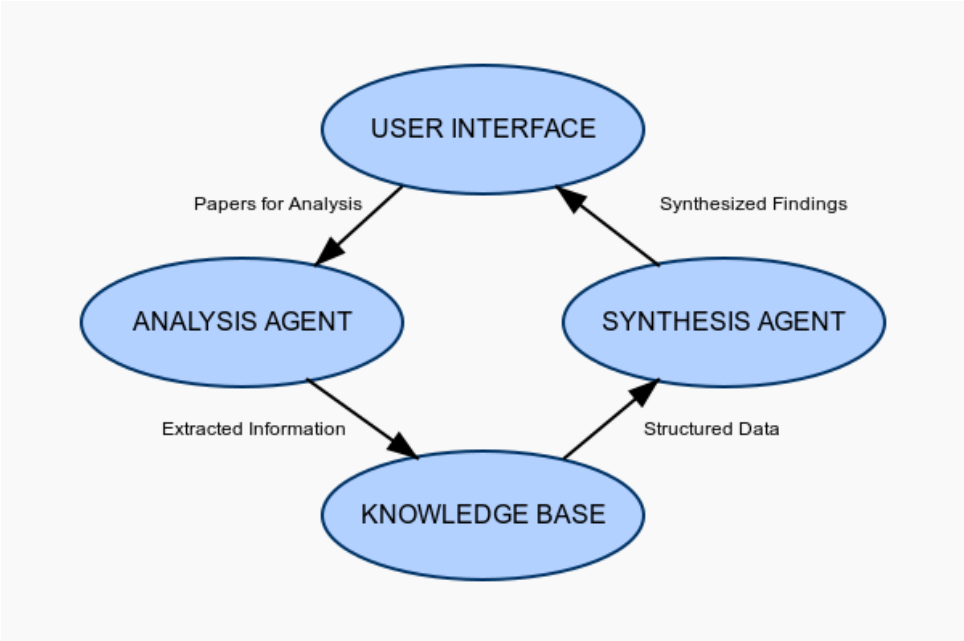


Figure 3: Preliminary Roles and Interactions for Scenario 2

### 1.1.3 Organizational Rules

The following organizational rules govern the interactions between agents in our system:

1. Each research query must be processed by at least one Search Agent:
   $\forall q.card(SEARCH\_AGENT(q)) \geq 1$
2. A Query Agent cannot evaluate its own search parameters:
   $\forall q.\forall a : plays(a, QUERY\_AGENT(q)) \Rightarrow \neg plays(a, SEARCH\_EVALUATOR(q))$
3. If a paper is found, it must be analyzed:
   $\forall p.participate(r, FindPaper(p)) \Rightarrow \Diamond initiate(r, AnalyzePaper(p))$
4. Every analyzed paper must be included in the knowledge base:
   $\forall p.participate(r, AnalyzePaper(p)) \Rightarrow \Diamond initiate(r, StoreInKnowledgeBase(p))$

## 1.2 Architectural Design

### 1.2.1 Role Model

Below is a detailed role schema for the Search Agent, one of the key roles in our system:

**Role Schema: SEARCH AGENT**

**Description:**

This role is responsible for querying multiple academic databases, handling authentication, optimizing search parameters, and collecting comprehensive search results.

**Protocols and Activities:**

| | | |
|---|---|---|
| QueryDatabase | OptimizeSearchTerms | HandleAuthentication |
| CollectResults | FormatResults | ReportSearchStats |

**Permissions:**

| | |
|---|---|
| reads | *query parameters, database credentials* |
| generates | *search results* |
| modifies | *search optimization parameters* |

**Responsibilities:**

**Liveness:**

SEARCH_AGENT = (HandleAuthentication → OptimizeSearchTerms → QueryDatabase → CollectResults → FormatResults → ReportSearchStats)^*

**Safety:**

- All required databases are successfully queried
- No duplicate results in final collection
- Authentication errors are properly handled and reported
- Search completeness metrics are generated

Figure 4: Role Schema for Search Agent

### 1.2.2 Interaction Model

The interaction model defines the communication protocols between agents:

| Protocol Name | Initiator | Partner | Inputs | Outputs |
|---|---|---|---|---|
| FormulateQuery | User Interface | Query Agent | Research question | Search parameters |
| QueryDatabase | Search Agent | Database | Search parameters | Raw results |
| AggregateResults | Results Agent | Search Agent | Raw results | Consolidated results |
| AnalyzePaper | Analysis Agent | Knowledge Base | Paper content | Structured analysis |
| SynthesizeFindings | Synthesis Agent | Knowledge Base | Multiple analyses | Synthesis report |
| PresentFindings | User Interface | Synthesis Agent | Synthesis report | Visualized findings |

Table 1: Interaction Model for Research Assistant MAS

### 1.2.3 Organizational Structure

The organizational structure of our MAS is as follows:

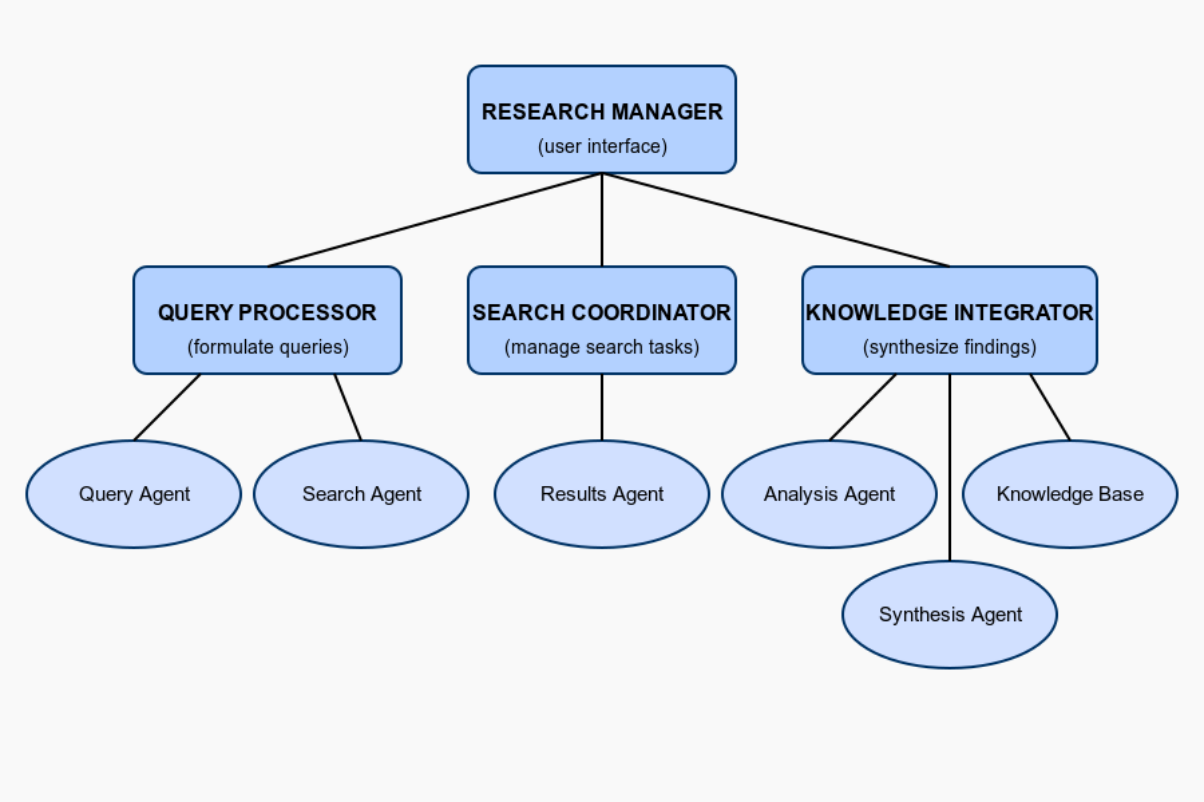


Figure 5: Organizational Structure for Research Assistant MAS

## 1.3 Detailed Design

### 1.3.1 Agent Model

The agent model maps roles to specific agent types:

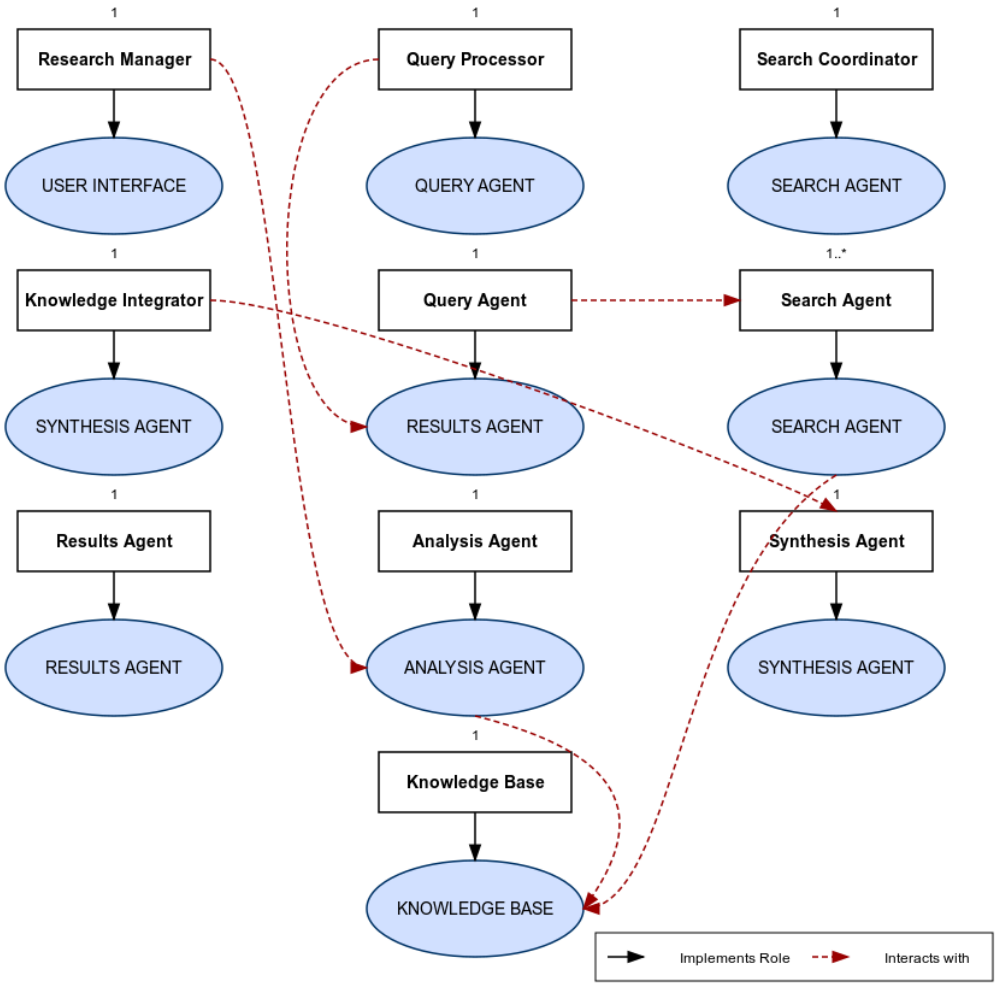


Figure 6: Agent Model for Research Assistant MAS

### 1.3.2 Service Model

The service model defines the services offered by each agent type:

| **Service** | **Input** | **Output** | **Pre-condition** | **Post-condition** |
|---|---|---|---|---|
| QueryDatabase | Search parameters, credentials | Raw search results | Authentication successful | Results collected from database |
| OptimizeSearch | Initial parameters, research context | Optimized query | Initial parameters provided | Expanded query with synonyms |
| CollectResults | Raw results from multiple databases | Consolidated result set | Search operations completed | Duplicates removed |
| AnalyzePaper | Paper content | Structured analysis (methods, findings) | Full text available | Key information extracted |
| SynthesizeFindings | Multiple paper analyses | Synthesis report with trends | Multiple papers analyzed | Connections between papers identified |

Table 2: Service Model for Research Assistant MAS