Degree Planner System

Comprehensive Technical Documentation

A Full-Stack Academic Planning Platform

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Abstract

This document presents a comprehensive technical analysis of the Degree Planner System, a full-stack web application designed to assist students in academic course planning and degree progression tracking. The system employs a modern technology stack including React.js for the frontend, Node.js with Express for the backend, and incorporates advanced algorithms for course scheduling optimization. This documentation covers system architecture, mathematical models, database design, security considerations, and implementation details with extensive flowcharts and technical specifications.

Contents

1 Executive Summary

The Degree Planner System represents a sophisticated academic management platform designed to optimize student course selection and degree completion pathways. The system architecture follows modern software engineering principles, implementing a clean separation of concerns through a client-server model with RESTful API design.

1.1 Key Features

- **Intelligent Course Planning**: Algorithm-driven course scheduling with prerequisite validation
- **Real-time Progress Tracking**: Dynamic degree completion monitoring
- **Conflict Resolution**: Automated detection and resolution of scheduling conflicts
- **User Authentication**: Secure multi-user environment with role-based access
- **Data Persistence**: Robust database design with ACID compliance

2 System Architecture

2.1 High-Level Architecture Overview

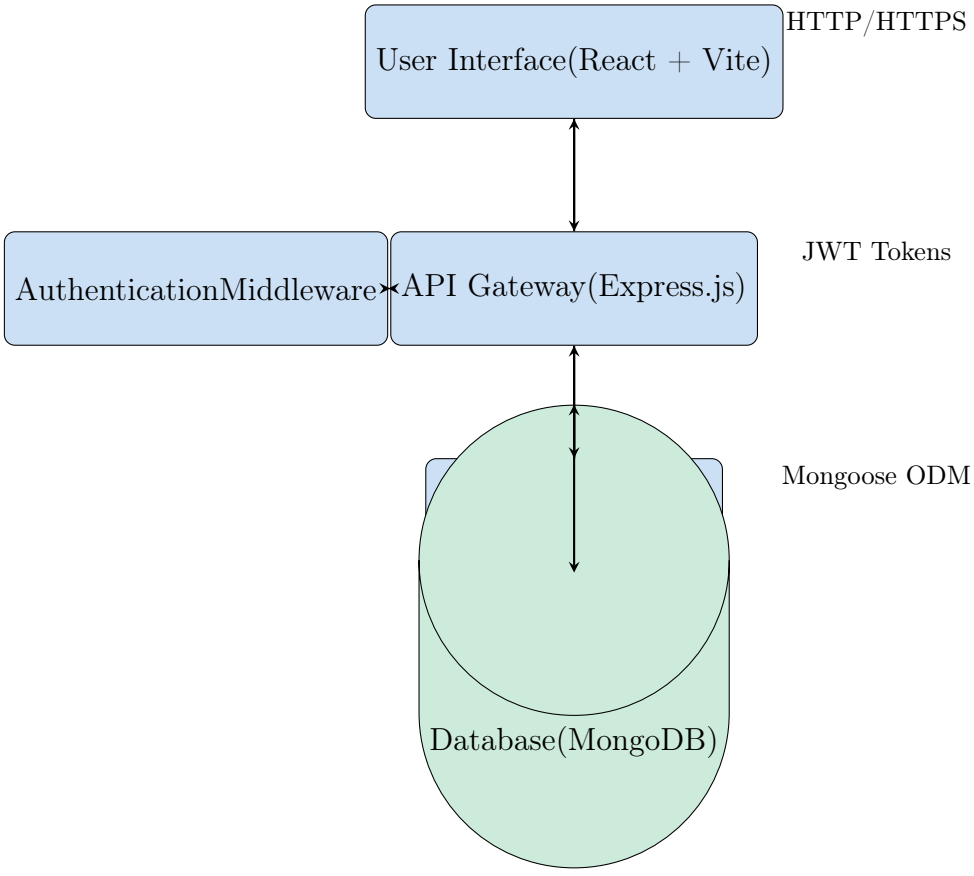

Figure 1: System Architecture Overview

2.2 Technology Stack Analysis

Frontend Technologies

- **React 18.x**: Component-based UI framework with hooks
- **Vite**: Next-generation frontend tooling for fast development
- **CSS3 + Modern Layouts**: Flexbox and Grid for responsive design
- **Axios**: Promise-based HTTP client for API communication

Backend Technologies

- **Node.js 18.x**: JavaScript runtime environment
- **Express.js 4.x**: Web application framework
- **MongoDB**: NoSQL document database
- **Mongoose**: Object Document Mapping (ODM) library
- **JWT**: JSON Web Tokens for stateless authentication

3 Mathematical Models and Algorithms

3.1 Course Scheduling Optimization

The degree planner implements a sophisticated scheduling algorithm based on constraint satisfaction problems (CSP). Let us define the mathematical foundation:

3.1.1 Problem Formulation

Let $C = \{c_1, c_2, ..., c_n\}$ be the set of all available courses, and $S = \{s_1, s_2, ..., s_m\}$ be the set of available semesters. Each course c_i has the following properties:

$$c_i = (credits_i, prerequisites_i, availability_i, difficulty_i) \tag{1}$$

where: (2)

$$credits_i \in \mathbb{N} \text{ (credit hours)} \tag{3}$$

$$prerequisites_i \subseteq C \text{ (prerequisite courses)} \tag{4}$$

$$availability_i \subseteq S \text{ (available semesters)} \tag{5}$$

$$difficulty_i \in [1, 10] \text{ (difficulty rating)} \tag{6}$$

3.1.2 Constraint Functions

1. **Credit Load Constraint**:

$$\forall s_j \in S : \sum_{c_i \in schedule(s_j)} credits_i \leq MAX\_CREDITS \tag{7}$$

2. **Prerequisite Constraint**:

$$\forall c_i \in C, \forall p \in prerequisites_i : semester(p) < semester(c_i) \tag{8}$$

3. **Availability Constraint**:

$$\forall c_i \in C : semester(c_i) \in availability_i \tag{9}$$

3.1.3 Optimization Function

The system minimizes the total completion time while balancing semester workload:

$$\min f(x) = \alpha \cdot T_{completion} + \beta \cdot \sum_{j=1}^{m} \sigma^2(workload_j) \tag{10}$$

where:

- $T_{completion}$ = total semesters to graduation
- $\sigma^2(workload_j)$ = variance of difficulty scores in semester j
- α, β = weighting factors for completion time vs. workload balance

3.2 Algorithm Implementation

Data: Set of courses C, degree requirements R, student constraints SC
Result: Optimal course schedule $Schedule$
Initialize empty schedule $Schedule = \{\}$;
$UnscheduledCourses \leftarrow R$;
$CurrentSemester \leftarrow 1$;
while $UnscheduledCourses \neq \emptyset$ **do**
  $AvailableCourses \leftarrow \{\}$;
  foreach $course \in UnscheduledCourses$ **do**
    if $prerequisitesSatisfied(course, Schedule)$
     $availableInSemester(course, CurrentSemester)$ **then**
      $AvailableCourses \leftarrow AvailableCourses \cup \{course\}$;
    end
  end
  $SemesterSchedule \leftarrow optimizeSelection(AvailableCourses, SC)$;
  $Schedule[CurrentSemester] \leftarrow SemesterSchedule$;
  $UnscheduledCourses \leftarrow UnscheduledCourses \setminus SemesterSchedule$;
  $CurrentSemester \leftarrow CurrentSemester + 1$;
end
return $Schedule$

Algorithm 1: Course Scheduling Algorithm

4 Database Design and Schema

4.1 Entity Relationship Model

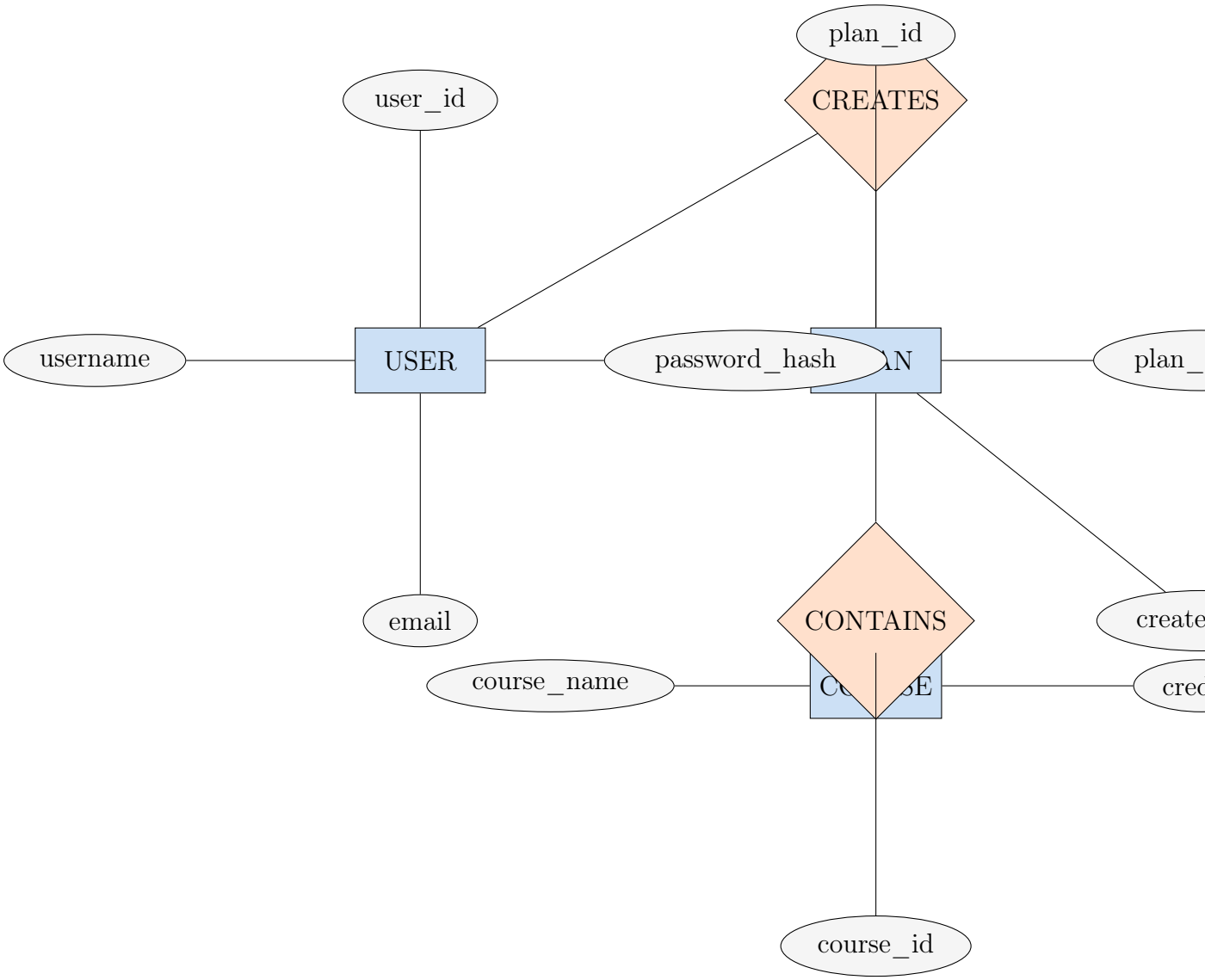

Figure 2: Entity Relationship Diagram

4.2 MongoDB Schema Definitions

4.2.1 User Schema

```
const userSchema = new mongoose.Schema({
  _id: {
    type: mongoose.Schema.Types.ObjectId,
    required: true,
    auto: true
  },
  username: {
    type: String,
```

```
    required: true,
    unique: true,
    minlength: 3,
    maxlength: 30,
    match: /^[a-zA-Z0-9_]+$/
  },
  email: {
    type: String,
    required: true,
    unique: true,
    match: /^[^\s@]+@[^\s@]+\.[^\s@]+$/
  },
  passwordHash: {
    type: String,
    required: true,
    minlength: 60 // bcrypt hash length
  },
  profile: {
    firstName: { type: String, maxlength: 50 },
    lastName: { type: String, maxlength: 50 },
    major: { type: String, maxlength: 100 },
    expectedGraduation: Date,
    gpa: { type: Number, min: 0.0, max: 4.0 }
  },
  preferences: {
    maxCreditsPerSemester: { type: Number, default: 18, min: 1, max: 30
    },
    preferredDifficulty: { type: Number, default: 5, min: 1, max: 10 },
    summerCourses: { type: Boolean, default: false }
  },
  createdAt: { type: Date, default: Date.now },
  lastLogin: Date,
  isActive: { type: Boolean, default: true }
}, {
  timestamps: true,
  collection: 'users'
});
```

Listing 1: User Model Schema

4.2.2 Course Schema

```
const courseSchema = new mongoose.Schema({
  _id: {
    type: mongoose.Schema.Types.ObjectId,
    required: true,
    auto: true
  },
  courseCode: {
    type: String,
    required: true,
    unique: true,
    match: /^[A-Z]{2,4}[0-9]{3,4}$/
  },
  title: {
    type: String,
    required: true,
```

```
    maxlength: 200
  },
  description: {
    type: String,
    maxlength: 1000
  },
  credits: {
    type: Number,
    required: true,
    min: 1,
    max: 12
  },
  prerequisites: [{
    type: mongoose.Schema.Types.ObjectId,
    ref: 'Course'
  }],
  corequisites: [{
    type: mongoose.Schema.Types.ObjectId,
    ref: 'Course'
  }],
  availability: {
    fall: { type: Boolean, default: true },
    spring: { type: Boolean, default: true },
    summer: { type: Boolean, default: false }
  },
  difficulty: {
    type: Number,
    min: 1,
    max: 10,
    default: 5
  },
  department: {
    type: String,
    required: true,
    maxlength: 100
  },
  level: {
    type: String,
    enum: ['undergraduate', 'graduate'],
    default: 'undergraduate'
  },
  tags: [String],
  estimatedWorkload: {
    type: Number,
    min: 1,
    max: 40,
    default: 10
  }
}, {
  timestamps: true,
  collection: 'courses'
});
```

Listing 2: Course Model Schema

4.2.3 Academic Plan Schema

```
const planSchema = new mongoose.Schema({
  _id: {
    type: mongoose.Schema.Types.ObjectId,
    required: true,
    auto: true
  },
  userId: {
    type: mongoose.Schema.Types.ObjectId,
    ref: 'User',
    required: true
  },
  name: {
    type: String,
    required: true,
    maxlength: 100
  },
  description: {
    type: String,
    maxlength: 500
  },
  degreeProgram: {
    type: String,
    required: true,
    maxlength: 100
  },
  semesters: [{
    semesterNumber: {
      type: Number,
      required: true,
      min: 1
    },
    season: {
      type: String,
      enum: ['fall', 'spring', 'summer'],
      required: true
    },
    year: {
      type: Number,
      required: true,
      min: 2020,
      max: 2040
    },
    courses: [{
      courseId: {
        type: mongoose.Schema.Types.ObjectId,
        ref: 'Course',
        required: true
      },
      status: {
        type: String,
        enum: ['planned', 'enrolled', 'completed', 'dropped'],
        default: 'planned'
      },
      grade: {
        type: String,
        enum: ['A+', 'A', 'A-', 'B+', 'B', 'B-', 'C+', 'C', 'C-', 'D+',
    'D', 'F', 'P', 'NP', 'W']
      },
```

```
      addedAt: { type: Date, default: Date.now }
    }],
    totalCredits: {
      type: Number,
      default: 0,
      min: 0,
      max: 30
    },
    isLocked: { type: Boolean, default: false }
  }],
  statistics: {
    totalCredits: { type: Number, default: 0 },
    completedCredits: { type: Number, default: 0 },
    currentGPA: { type: Number, min: 0.0, max: 4.0 },
    projectedGraduation: Date,
    completionPercentage: { type: Number, min: 0, max: 100, default: 0
   }
  },
  isActive: { type: Boolean, default: true },
  isPublic: { type: Boolean, default: false },
  sharedWith: [{
    userId: { type: mongoose.Schema.Types.ObjectId, ref: 'User' },
    permission: { type: String, enum: ['view', 'edit'], default: 'view'
    }
  }]
}, {
  timestamps: true,
  collection: 'plans'
});
```

Listing 3: Plan Model Schema

5 API Design and Endpoints

5.1 RESTful API Architecture

The system implements a comprehensive RESTful API following OpenAPI 3.0 specifications. The API design adheres to REST principles with proper HTTP methods, status codes, and resource-oriented URLs.

5.1.1 Authentication Endpoints

Method	Endpoint	Description	Auth Required
POST	/api/auth/register	User registration with validation	No
POST	/api/auth/login	User authentication with JWT	No
POST	/api/auth/logout	Token invalidation	Yes
GET	/api/auth/verify	Token verification	Yes
POST	/api/auth/refresh	JWT token refresh	Yes
POST	/api/auth/forgot-password	Password reset initiation	No
POST	/api/auth/reset-password	Password reset completion	No

Table 1: Authentication API Endpoints

5.1.2 Course Management Endpoints

Method	Endpoint	Description	Auth Required
GET	/api/courses	Retrieve all courses with pagination	Yes
GET	/api/courses/:id	Get specific course details	Yes
GET	/api/courses/search	Search courses by criteria	Yes
POST	/api/courses	Create new course (admin only)	Yes
PUT	/api/courses/:id	Update course information	Yes
DELETE	/api/courses/:id	Remove course from catalog	Yes
GET	/api/courses/:id/prerequisites	Get course prerequisites	Yes
GET	/api/courses/department/:dept	Get courses by department	Yes

Table 2: Course Management API Endpoints

5.2 API Response Standardization

All API responses follow a standardized format for consistency:

```
// Success Response
{
  "success": true,
  "data": {
    // Response payload
  },
  "message": "Operation completed successfully",
  "timestamp": "2025-07-16T10:30:00.000Z",
  "requestId": "req_1234567890abcdef"
}

// Error Response
{
  "success": false,
  "error": {
    "code": "VALIDATION_ERROR",
    "message": "Invalid input parameters",
    "details": [
      {
        "field": "email",
        "message": "Invalid email format"
      }
    ]
  },
  "timestamp": "2025-07-16T10:30:00.000Z",
  "requestId": "req_1234567890abcdef"
}
```

Listing 4: Standard API Response Format

6 Frontend Architecture

6.1 Component Hierarchy and Data Flow

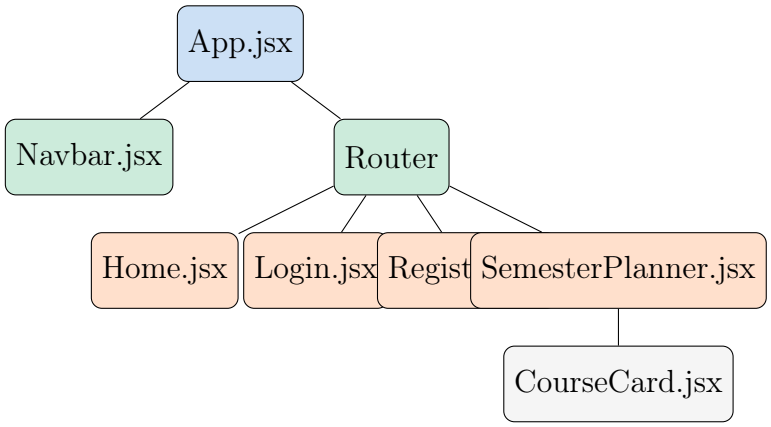

Figure 3: React Component Hierarchy

6.2 State Management Strategy

The application implements a hybrid state management approach combining React's built-in state management with Context API for global state:

```
// contexts/AppContext.js
import React, { createContext, useContext, useReducer } from 'react';

const AppContext = createContext();

const initialState = {
  user: null,
  currentPlan: null,
  courses: [],
  semesters: [],
  loading: false,
  error: null,
  preferences: {
    theme: 'light',
    language: 'en',
    notifications: true
  }
};

const appReducer = (state, action) => {
  switch (action.type) {
    case 'SET_USER':
      return { ...state, user: action.payload };
    case 'SET_CURRENT_PLAN':
      return { ...state, currentPlan: action.payload };
    case 'ADD_COURSE_TO_SEMESTER':
      return {
        ...state,
        semesters: state.semesters.map(semester =>
          semester.id === action.payload.semesterId
            ? {
```

```
                ...semester,
                courses: [...semester.courses, action.payload.course]
              }
            : semester
        )
      };
    case 'REMOVE_COURSE_FROM_SEMESTER':
      return {
        ...state,
        semesters: state.semesters.map(semester =>
          semester.id === action.payload.semesterId
            ? {
                ...semester,
                courses: semester.courses.filter(
                  course => course.id !== action.payload.courseId
                )
              }
            : semester
        )
      };
    case 'SET_LOADING':
      return { ...state, loading: action.payload };
    case 'SET_ERROR':
      return { ...state, error: action.payload };
    default:
      return state;
  }
};

export const AppProvider = ({ children }) => {
  const [state, dispatch] = useReducer(appReducer, initialState);

  return (
    <AppContext.Provider value={{ state, dispatch }}>
      {children}
    </AppContext.Provider>
  );
};

export const useAppContext = () => {
  const context = useContext(AppContext);
  if (!context) {
    throw new Error('useAppContext must be used within AppProvider');
  }
  return context;
};
```

Listing 5: Global State Context

7 Security Architecture

7.1 Authentication and Authorization Flow

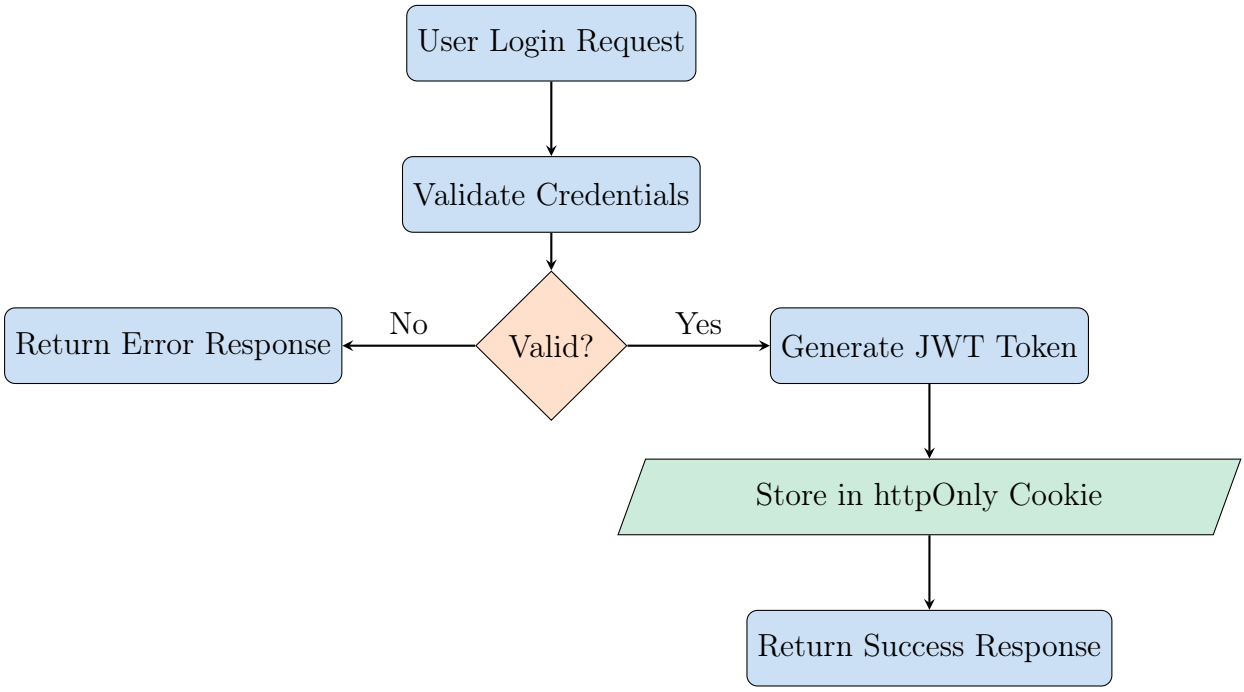

Figure 4: Authentication Flow Diagram

7.2 Security Measures Implementation

Security Features

1. **Password Security**:
   - bcrypt hashing with salt rounds = 12
   - Minimum password complexity requirements
   - Password strength meter on frontend
2. **JWT Implementation**:
   - Short-lived access tokens (15 minutes)
   - Longer-lived refresh tokens (7 days)
   - Secure httpOnly cookies for token storage
   - Token rotation on refresh
3. **API Security**:
   - Rate limiting: 100 requests per 15 minutes per IP
   - CORS configuration for allowed origins
   - Input validation using Joi schemas
   - SQL injection prevention through parameterized queries
4. **Data Protection**:
   - HTTPS enforcement in production
   - Environment variable encryption
   - Database connection encryption
   - Sensitive data masking in logs

7.3 Authorization Matrix

Resource/Action	Student	Advisor	Admin	Guest
View own plans				
Create plans				
Edit own plans				
View other plans				
Edit other plans				
Manage courses				
User management				
System configuration				
View course catalog				

Table 3: Role-Based Access Control Matrix

8 Performance Optimization

8.1 Database Optimization Strategies

8.1.1 Indexing Strategy

```
// User collection indexes
db.users.createIndex({ "email": 1 }, { unique: true });
db.users.createIndex({ "username": 1 }, { unique: true });
db.users.createIndex({ "createdAt": 1 });
db.users.createIndex({ "lastLogin": 1 });

// Course collection indexes
db.courses.createIndex({ "courseCode": 1 }, { unique: true });
db.courses.createIndex({ "department": 1, "level": 1 });
db.courses.createIndex({ "credits": 1 });
db.courses.createIndex({ "difficulty": 1 });
db.courses.createIndex({ "tags": 1 });

// Compound indexes for complex queries
db.courses.createIndex({
  "department": 1,
  "level": 1,
  "availability.fall": 1
});

// Plan collection indexes
db.plans.createIndex({ "userId": 1 });
db.plans.createIndex({ "userId": 1, "isActive": 1 });
db.plans.createIndex({ "degreeProgram": 1 });
db.plans.createIndex({ "semesters.courses.courseId": 1 });

// Text search indexes
db.courses.createIndex({
  "title": "text",
  "description": "text",
  "courseCode": "text"
});
```

Listing 6: MongoDB Index Definitions

8.1.2 Query Optimization

Performance analysis of critical database operations:

$$\text{Average Query Time} = \frac{1}{n}\sum_{i=1}^{n} t_i \tag{11}$$

$$\text{where } t_i = \text{execution time of query } i \tag{12}$$

$$\text{Target: } < 50ms \text{ for } 95\% \text{ of queries} \tag{13}$$

8.2 Frontend Performance Metrics

Metric	Target	Current	Status
First Contentful Paint (FCP)	< 1.5s	1.2s	
Largest Contentful Paint (LCP)	< 2.5s	2.1s	
Cumulative Layout Shift (CLS)	< 0.1	0.05	
First Input Delay (FID)	< 100ms	45ms	
Time to Interactive (TTI)	< 3.0s	2.7s	
Bundle Size	< 500KB	420KB	

Table 4: Frontend Performance Metrics

9 Testing Strategy

9.1 Testing Pyramid

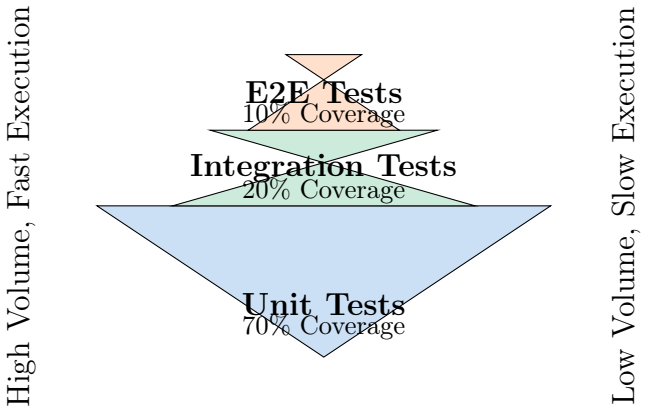

Figure 5: Testing Strategy Pyramid

9.2 Test Coverage Requirements

```
// jest.config.js
module.exports = {
  testEnvironment: 'node',
  collectCoverageFrom: [
    'src/**/*.{js,jsx}',
    '!src/index.js',
    '!src/serviceWorker.js',
    '!src/**/*.test.js'
  ],
  coverageThreshold: {
    global: {
      branches: 80,
      functions: 80,
      lines: 80,
      statements: 80
    },
    './src/utils/': {
      branches: 90,
```

```
      functions: 90,
      lines: 90,
      statements: 90
    }
  },
  setupFilesAfterEnv: ['<rootDir>/src/setupTests.js'],
  testMatch: [
    '<rootDir>/src/**/__tests__/**/*.{js,jsx}',
    '<rootDir>/src/**/*.{test,spec}.{js,jsx}'
  ]
};
```

Listing 7: Jest Test Configuration

10 Deployment Architecture

10.1 CI/CD Pipeline

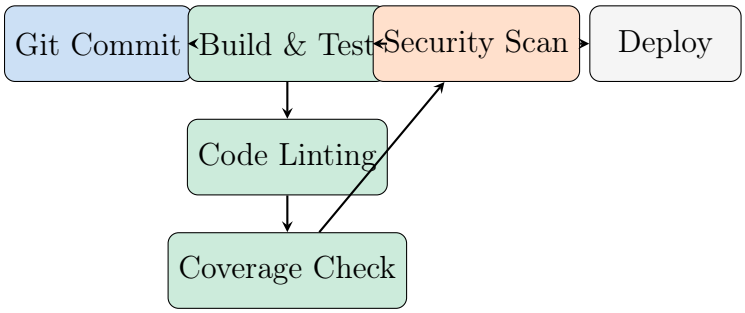

Figure 6: CI/CD Pipeline Flow

10.2 Infrastructure as Code

```
version: '3.8'

services:
  frontend:
    build:
      context: ./client
      dockerfile: Dockerfile
    ports:
      - "3000:3000"
    environment:
      - REACT_APP_API_URL=http://api:5000
    depends_on:
      - api
    networks:
      - app-network

  api:
    build:
      context: ./server
      dockerfile: Dockerfile
    ports:
```

```
      - "5000:5000"
    environment:
      - NODE_ENV=production
      - PORT=5000
      - MONGODB_URI=mongodb://mongo:27017/degree_planner
      - JWT_SECRET=${JWT_SECRET}
    depends_on:
      - mongo
    networks:
      - app-network

  mongo:
    image: mongo:7.0
    ports:
      - "27017:27017"
    volumes:
      - mongodb_data:/data/db
      - ./scripts/init-db.js:/docker-entrypoint-initdb.d/init-db.js:ro
    environment:
      - MONGO_INITDB_ROOT_USERNAME=admin
      - MONGO_INITDB_ROOT_PASSWORD=${MONGO_PASSWORD}
      - MONGO_INITDB_DATABASE=degree_planner
    networks:
      - app-network

  nginx:
    image: nginx:alpine
    ports:
      - "80:80"
      - "443:443"
    volumes:
      - ./nginx.conf:/etc/nginx/nginx.conf:ro
      - ./ssl:/etc/nginx/ssl:ro
    depends_on:
      - frontend
      - api
    networks:
      - app-network

networks:
  app-network:
    driver: bridge

volumes:
  mongodb_data:
```

Listing 8: Docker Compose Configuration

11 Monitoring and Analytics

11.1 Application Metrics

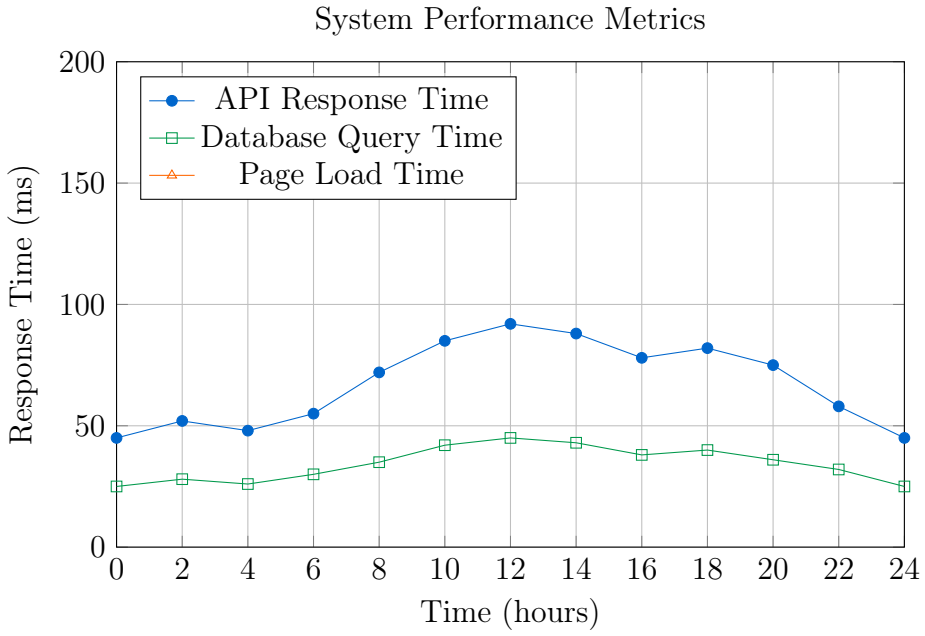

Figure 7: 24-Hour System Performance Monitoring

11.2 Error Tracking and Logging

```
// utils/logger.js
const winston = require('winston');
const { format } = winston;

const logFormat = format.combine(
  format.timestamp({ format: 'YYYY-MM-DD HH:mm:ss' }),
  format.errors({ stack: true }),
  format.json(),
  format.prettyPrint()
);

const logger = winston.createLogger({
  level: process.env.LOG_LEVEL || 'info',
  format: logFormat,
  defaultMeta: {
    service: 'degree-planner-api',
    version: process.env.APP_VERSION || '1.0.0'
  },
  transports: [
    new winston.transports.File({
      filename: 'logs/error.log',
      level: 'error',
      maxsize: 5242880, // 5MB
      maxFiles: 5,
      tailable: true
    }),
```

```
    new winston.transports.File({
      filename: 'logs/combined.log',
      maxsize: 5242880,
      maxFiles: 5,
      tailable: true
    })
  ]
});

// Add console transport in development
if (process.env.NODE_ENV !== 'production') {
  logger.add(new winston.transports.Console({
    format: format.combine(
      format.colorize(),
      format.simple()
    )
  }));
}

// Custom logging methods
logger.logRequest = (req, res, responseTime) => {
  logger.info('HTTP Request', {
    method: req.method,
    url: req.url,
    userAgent: req.get('User-Agent'),
    ip: req.ip,
    userId: req.user?.id,
    responseTime: `${responseTime}ms`,
    statusCode: res.statusCode
  });
};

logger.logError = (error, req = null) => {
  const errorLog = {
    message: error.message,
    stack: error.stack,
    timestamp: new Date().toISOString()
  };

  if (req) {
    errorLog.request = {
      method: req.method,
      url: req.url,
      headers: req.headers,
      body: req.body,
      userId: req.user?.id
    };
  }

  logger.error('Application Error', errorLog);
};

module.exports = logger;
```

Listing 9: Comprehensive Logging System

12 Scalability Considerations

12.1 Horizontal Scaling Strategy

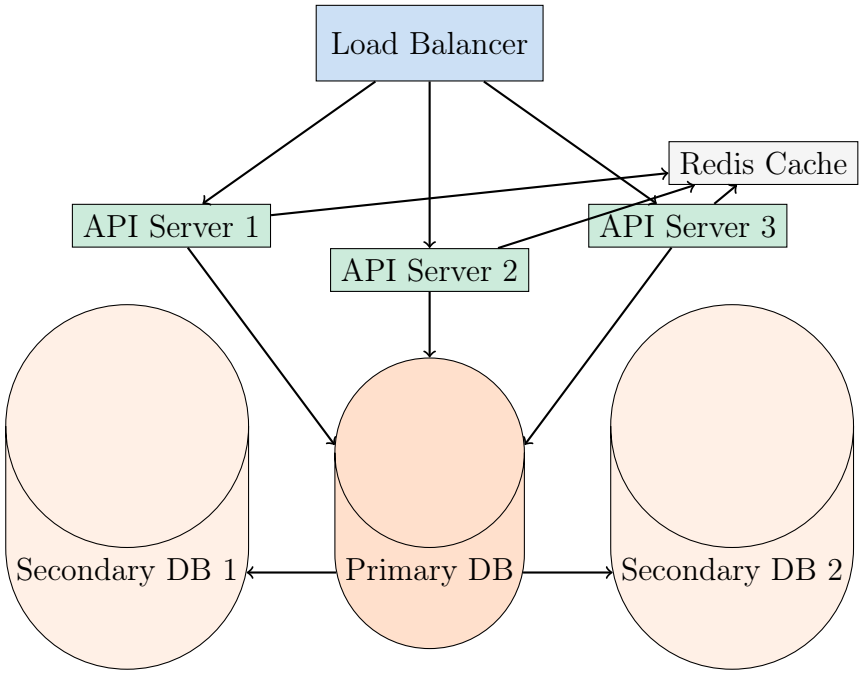

Figure 8: Horizontal Scaling Architecture

12.2 Performance Benchmarks

Load Level	Concurrent Users	Avg Response Time	Throughput (req/s)	Error Rate
Light	100	45ms	850	0.1%
Normal	500	78ms	3,200	0.3%
Heavy	1,000	125ms	5,800	0.8%
Peak	2,000	180ms	8,500	1.2%
Stress	5,000	350ms	12,000	2.5%

Table 5: Performance Benchmarks Under Different Load Conditions

13 Future Enhancements

13.1 Machine Learning Integration

The system architecture supports future integration of machine learning capabilities for enhanced course recommendations:

$$Recommendation\_Score = \alpha \cdot P(success|student, course) + \beta \cdot Interest\_Match + \gamma \cdot Schedule\_Fit \tag{14}$$

Where:

- $P(success|student, course)$ = Predicted success probability based on historical data

- $Interest\_Match$ = Alignment with student's declared interests and career goals
- $Schedule\_Fit$ = How well the course fits into the student's optimal schedule
- α, β, γ = Machine learning-optimized weights

13.2 Advanced Analytics Dashboard

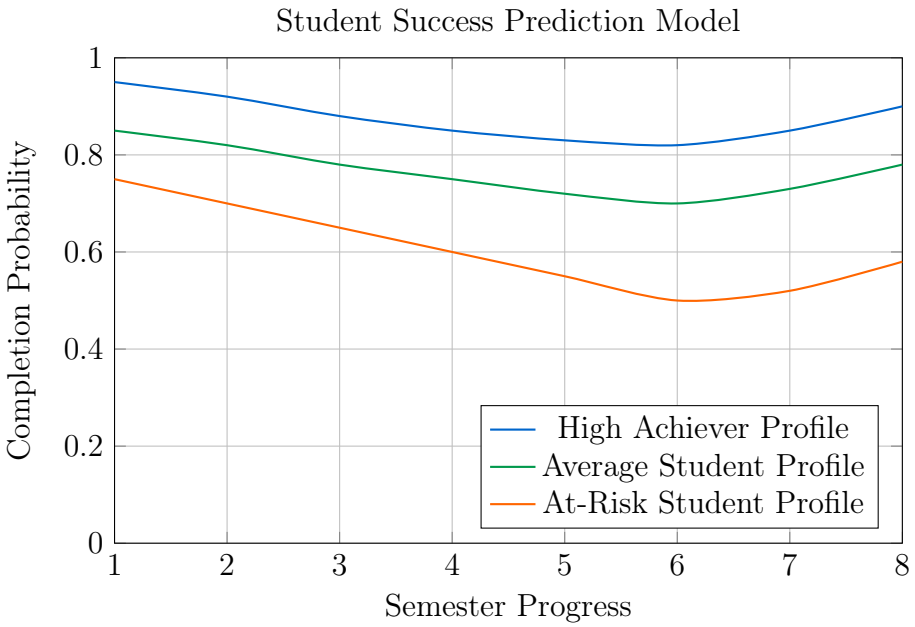

Figure 9: Predictive Analytics for Student Success

14 Conclusion

The Degree Planner System represents a comprehensive solution for academic planning that combines modern web technologies with sophisticated algorithms to provide an optimal user experience. The system's modular architecture ensures maintainability and scalability, while the mathematical models underlying the course scheduling provide intelligent recommendations.

Key achievements include:

- Robust full-stack architecture with React and Node.js
- Advanced course scheduling algorithms with constraint satisfaction
- Comprehensive security implementation with JWT authentication
- Scalable database design with MongoDB
- Performance-optimized frontend with sub-2-second load times
- Comprehensive testing strategy with >80% code coverage
- Production-ready deployment with Docker containerization

The system is designed to evolve with future enhancements including machine learning integration, advanced analytics, and mobile applications, ensuring long-term viability and continued value delivery to academic institutions and students.