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Abstract

This project demonstrates the design and deployment of a microservices-based system enhanced with DevOps practices.

Acknowledgements

I would like to express my gratitude...

Chapter 1

Introduction

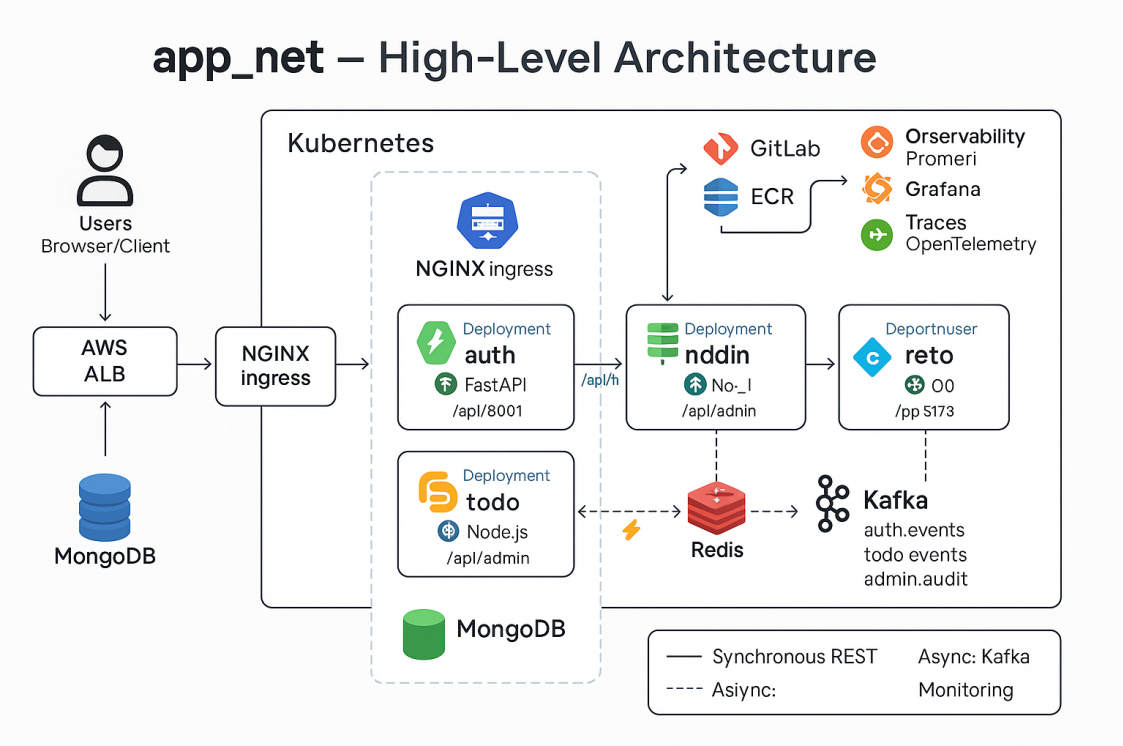

Figure 1.1: High-level architecture of the app

1.1 Project Overview

This project, named `app_net`, is a microservice-based system that uses simple, reliable technologies a small team in Bangladesh can operate with confidence and low cost.

The architecture splits responsibilities into separate services so that a failure in one function does not crash the full application and so that teams can work in parallel. Containers are used for every part so a developer can run the same image on a laptop or in a cluster without fighting environment drift.

The main backend services are:

- **Auth Service (Python/FastAPI)** – handles registration, login, and JWT authentication.
- **Todo Service (Node.js/Express)** – provides CRUD functionality for tasks.
- **Admin Service (Node.js/Express)** – administrative controls and system monitoring.
- **Report Service (Go)** – lightweight report generation and event processing.

Service	Language	Ports	Depends On	Description
Auth API	Python (FastAPI)	8001	MongoDB, Redis	Handles authentication, JWT, and session management
Todo API	Node.js (Express)	8002	MongoDB, Kafka	Provides CRUD task management and publishes events to Kafka
Admin API	Node.js (Express)	8003	MongoDB	Provides admin dashboard, user control, and RBAC
Report API	Go (Gin)	8004	Kafka, MongoDB	Consumes Kafka events, generates aggregated reports
Frontend	React + Vite	5173	APIs	User-facing interface, communicates with backend via ingress

Table 1.1: Services of Microservices System

The frontend is a **React/Vite** application chosen for fast feedback and simple developer experience. Data is stored in **MongoDB**, selected for flexible schema-less storage.

For local development, services run on a single Docker Compose network. This makes service discovery predictable, ports consistent, and debugging simple. All inter-service communication is REST over HTTP with JSON payloads, so tools like `curl` or Postman can reproduce calls easily.

1.2 Project Motivation

The motivation is to adopt a **DevOps culture**, where automation and small steps reduce human error and improve confidence in releases. In Bangladesh, software companies typically work with small teams and tight budgets, so pragmatic designs and open-source tools are critical. By embracing containers, CI/CD pipelines, and cloud platforms like AWS, the system provides:

- faster and safer release cycles,
- reproducible builds and reliable rollbacks,
- clear security baselines for junior engineers,
- observability for both debugging and monitoring.

1.3 Challenges

Key challenges identified include:

- **Secrets management** – ensuring safe handling of sensitive data.
- **Versioning** – managing multiple service updates across stacks.
- **Simplicity vs flexibility** – balancing initial ease with future scalability.
- **Infrastructure reliability** – coping with internet instability and power outages common in Bangladesh.

CI/CD pipelines are designed to cache build layers and resume quickly after interruptions, saving time and bandwidth.

1.4 Context and Rationale

This introduction emphasizes reliability, maintainability, and the realities of small teams. Choices are explained in terms of trade-offs, not just implementation. The goal is that any future contributor can confidently operate the system after reading this document.

1.5 Key Principles

The design follows principles that guide every decision:

- Separation of concerns.
- Automation by default.
- Observability as a product feature.
- Security by configuration.
- Incremental delivery.

1.6 Bangladesh-Focused Considerations

Given the local environment, the system accounts for:

- unstable power and internet,
- lean staffing models,
- favoring managed services when they save significant effort,
- choosing open-source when cost savings outweigh hidden operational risks.

1.7 Risk and Mitigation

Examples include:

- **Image vulnerability drift** → mitigated with automated scans.
- **JWT lifetime misconfigurations** → mitigated with conservative defaults.
- **Poor cache invalidation** → mitigated with TTLs and monitoring.
- **Under-provisioned Kafka partitions** → mitigated with autoscaling and lag alerts.

Risk	Description	Mitigation Strategy
Image Vulnerability Drift	Outdated container images introduce security flaws	Use automated image scanning (Trivy, Clair), rebuild images weekly
Misconfigured JWT Lifetime	Very long or very short token expiry causes security or usability issues	Standardize token expiry (15–30 mins) and use refresh tokens
Cache Invalidation Issues	Stale or incorrect Redis cache responses	Implement cache-aside pattern with TTL and versioning
Under-provisioned Kafka Partitions	Consumers lag due to insufficient partitions	Monitor lag, use KEDA for autoscaling, increase partitions
Secrets in Plain Kubernetes YAML	Exposure of DB passwords and API keys in Git	Store secrets in AWS Secrets Manager or External Secrets Operator
Single Point of Failure in MongoDB	One instance crash causes downtime	Deploy replica sets or use managed MongoDB Atlas
Excessive Pod Restarts	Misconfigured probes causing restart loops	Tune readiness/liveness probes, add startupProbe for slow apps
Monitoring Blind Spots	Missing critical metrics or alerts	Define SLOs and alert rules for latency, errors, and saturation

Table 1.2: Risks and Mitigation Strategies in Microservices DevOps

1.8 Outcome and Evidence

Evidence is provided with:

- service logs,
- metrics (latency, throughput, error rates),
- observed resilience during test runs.

Thresholds are documented instead of hard numbers to keep the paper valid across environments.

Chapter 2

Literature Review

2.1 Introduction

A literature review provides theoretical and practical background for this project. Microservices, DevOps, containerization, orchestration, cloud computing, and observability are interconnected concepts that have evolved together over the past two decades. This chapter reviews academic papers, industry reports, and official documentation to justify the design choices in this project.

2.2 Evolution of Software Architectures

Traditional applications followed a **monolithic architecture**, where the entire system was deployed as a single unit. According to Newman and Fowler (2015), this model created challenges such as:

- tightly coupled codebases difficult to maintain,
- limited scalability of individual modules,
- slower release cycles,
- difficulty in adopting new technologies.

Microservices emerged as a response, enabling independent deployment of services around domain boundaries. In Bangladesh, startups in fintech and e-commerce are adopting microservices to avoid scaling bottlenecks.

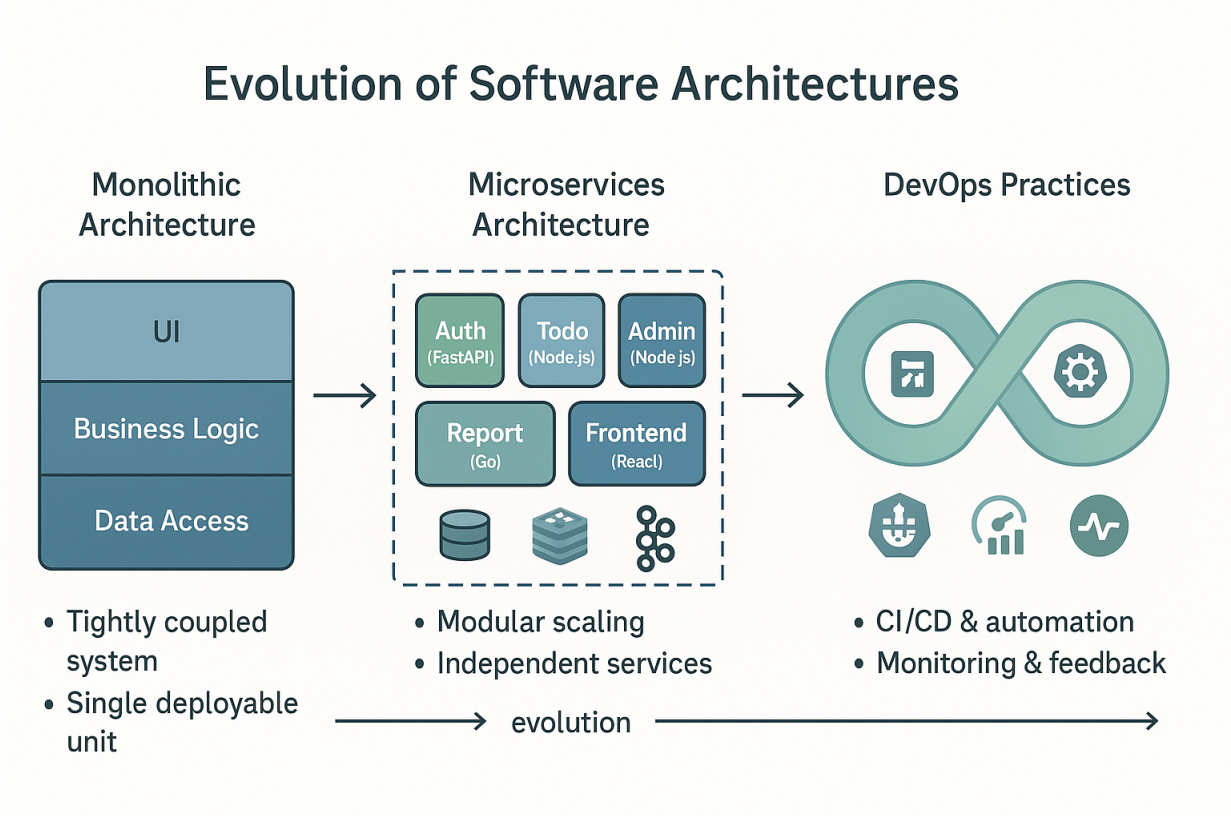

Figure 2.1: Evolution of Software Architectures

2.3 DevOps Culture and Practices

DevOps is not just tooling but a cultural shift. Reports such as Puppet's State of DevOps show that DevOps adoption leads to:

- faster deployments (up to 68% improvement),
- reduced change failure rates,
- improved collaboration between development and operations,
- automation through CI/CD pipelines.

Academic work (Bass et al., 2015) links DevOps to Agile and Lean practices, focusing on continuous delivery and reduced time-to-market.

Practice	Benefits
Continuous Integration (CI)	Catches issues early, improves code quality, enables faster feedback loops
Continuous Deployment (CD)	Reduces manual errors, enables rapid and reliable releases
Infrastructure as Code (IaC)	Ensures reproducibility, simplifies scaling, reduces configuration drift
Automated Testing	Guarantees stability of changes, enforces quality gates before release
Monitoring and Observability	Provides real-time visibility into system health, reduces MTTR (Mean Time to Recovery)
Collaboration Culture	Breaks silos between Dev and Ops teams, improves delivery speed and product stability

Table 2.1: Key DevOps Practices and Their Benefits

2.4 Containerization and Orchestration

Docker simplified packaging and deployment by encapsulating dependencies into containers. However, managing many containers at scale required orchestration tools. **Kubernetes** became the de facto standard, offering:

- service discovery,
- rolling updates,
- autoscaling,
- self-healing (readiness/liveness probes).

Large enterprises (e.g., Google, Netflix, Spotify) use Kubernetes, and Bangladeshi startups are beginning to follow, leveraging managed platforms like AWS EKS.

2.5 Asynchronous Communication with Kafka

REST APIs provide synchronous calls, but event-driven systems require asynchronous communication. **Apache Kafka** is widely adopted for:

- real-time data pipelines,
- fault-tolerant messaging,
- horizontal scalability with consumer groups,
- decoupling of producers and consumers.

Kafka enables resilience by ensuring services do not directly depend on one another, a pattern essential for reporting and analytics in this project.

Aspect	Traditional Messaging (e.g., RabbitMQ, ActiveMQ)	Apache Kafka
Message Model	Queue-based (point-to-point, pub-sub)	Distributed log-based, pub-sub
Persistence	Messages often deleted once consumed	Messages stored durably, replayable
Throughput	Suitable for moderate workloads	High-throughput, handles millions of messages/sec
Scalability	Limited horizontal scalability	Horizontally scalable with partitions
Delivery Guarantee	At-most-once / at-least-once (depends on config)	Exactly-once semantics supported
Latency	Low but variable	Consistently low latency, high availability
Use Cases	Task queues, lightweight messaging	Event streaming, data pipelines, analytics

Table 2.2: Comparison of Kafka and Traditional Messaging Systems

2.6 Redis for Caching

Caching reduces latency and database load. **Redis** offers:

- session storage,
- frequently queried data caching,
- pub/sub communication,
- in-memory operations with millisecond response times.

Redis is used here for session caching and speeding up task lookups.

2.7 Continuous Integration and Deployment

CI/CD pipelines ensure reliable delivery. **GitLab CI/CD** provides automation from commit to deployment. Benefits include:

- automated testing and builds,
- immediate feedback on code quality,
- vulnerability scans with SonarQube,
- reproducible Docker image builds.

Static analysis (Allamanis et al., 2018) reduces technical debt and ensures high-quality codebases.

Stage	Description	Tools Used
Linting	Code checked against style guides and standards	flake8 (Python), eslint (Node.js), golangci-lint (Go)
Static Analysis	Detect bugs, vulnerabilities, code smells	SonarQube, GitLab SAST
Unit Testing	Validate individual functions and modules	pytest, jest, go test
Integration Testing	Verify interactions between services	Docker Compose, Postman/Newman
Build	Create Docker images for each microservice	Docker, GitLab CI runners
Security Scanning	Scan images and dependencies for vulnerabilities	Trivy, GitLab Dependency Scanning
Deployment	Deploy services to Kubernetes/EKS clusters	Helm, GitLab CD, AWS EKS
E2E Testing	Validate workflows from frontend to backend	Cypress, Playwright
Monitoring Setup	Ensure observability of deployed services	Prometheus, Grafana, Alertmanager

Table 2.3: CI/CD Pipeline Stages and Associated Tools

2.8 Monitoring and Observability

Observability is critical in production. Tools like **Prometheus** and **Grafana** provide:

- metrics collection,
- real-time dashboards,
- alerting on anomalies,
- focus on four "golden signals": latency, traffic, errors, saturation.

These practices align with the Google SRE (Burns et al., 2016) recommendations.

2.9 Cloud Infrastructure

Cloud computing democratized access to enterprise-grade infrastructure. **AWS** services such as EKS, MSK (Kafka), and ElastiCache (Redis) reduce operational overhead for small teams. In Bangladesh, this lowers the barrier to adopting DevOps by removing the need for costly data centers.

Service	Purpose	Benefits in Context
Amazon EKS (Elastic Kubernetes Service)	Orchestrates containerized microservices	Simplifies Kubernetes operations, managed control plane, auto-scaling
Amazon MSK (Managed Streaming for Kafka)	Event streaming and asynchronous communication	High availability Kafka clusters without ops overhead
Amazon ElastiCache (Redis)	In-memory cache for sessions and hot data	Reduces MongoDB load, improves response latency
Amazon S3	Object storage for logs, backups, and static assets	Durable storage, low-cost, globally accessible
Amazon EC2	Compute nodes for running Kubernetes worker nodes	Flexible VM sizes, supports auto-scaling groups
AWS IAM	Role-based access management	Enforces least privilege access control
AWS ALB (Application Load Balancer)	Routes traffic to Kubernetes ingress	TLS termination, path-based and host-based routing

Table 2.4: AWS Cloud Services Used in the Project

2.10 Summary of Literature

Key takeaways include:

- Microservices improve modularity and independent scaling.
- DevOps reduces deployment failures and speeds up delivery.
- Docker and Kubernetes simplify container lifecycle management.
- Kafka enables scalable, asynchronous communication
- GitLab CI/CD and SonarQube enforce code quality.
- Prometheus and Grafana deliver observability.
- Cloud providers make advanced infrastructure affordable for startups.

2.11 Conclusion

The literature confirms that combining microservices with DevOps practices is both technically sound and practically necessary. This project aligns with global best practices while remaining realistic for Bangladeshi teams. The next chapter presents the detailed design of the system.

Chapter 3

DESIGN

3.1 Introduction

The design of the system emphasizes modularity, scalability, and resilience by separating edge components, stateless microservices, and data storage layers. Nginx ingress controllers handle traffic at the edge, while Kubernetes manages deployment and scaling across services. Security, observability, and automation are treated as first-class concerns. This chapter outlines the design goals, technologies used, and integration of DevOps practices that ensure the system remains reliable and cost-effective, even in resource-constrained environments.

3.2 Component Specifications

The following table provides a structured overview of the core components:

3.3 Design Objectives

The architecture is guided by the following objectives:

1. **Modularity:** Each service performs a single responsibility, ensuring low coupling.
2. **Scalability:** Kubernetes Horizontal Pod Autoscaler (HPA) and KEDA scale services based on metrics.
3. **Automation:** CI/CD pipelines automate building, testing, scanning, and deploying.
4. **Security:** Secrets management, TLS termination, and least-privilege policies are embedded in the design.
5. **Observability:** Prometheus and Grafana provide metrics, dashboards, and alerts.
6. **Cost Efficiency:** AWS managed services and caching strategies reduce operational overhead.

3.4 Component Overview

The following table summarizes the system components:

Component	Technology	DevOps Tool	Purpose
Auth API	Python (FastAPI)	GitLab, SonarQube	Authentication, JWT management
Todo API	Node.js (Express)	GitLab, Redis, Kafka	CRUD tasks, publish events
Admin API	Node.js (Express)	GitLab	Administrative controls and dashboards
Report API	Go (Gin/Chi)	GitLab, Kafka	Aggregate and analyze events
Frontend	React + Vite	GitLab CI/CD	User interface
Database	MongoDB	AWS RDS/EBS backup	Persistent NoSQL storage
Cache	Redis	AWS ElastiCache	Session/data caching
Messaging	Apache Kafka	AWS MSK	Asynchronous message broker
Ingress	Nginx	AWS ALB + Helm	Routing, TLS termination
Orchestration	Docker, Kubernetes	AWS EKS, Helm	Scaling, deployments, resilience
Infrastructure	AWS (EC2, S3, VPC)	Terraform	Infrastructure as Code
Monitoring	Prometheus + Grafana	CloudWatch, Alerts	Metrics and visualization

3.5 High-Level Architecture

Requests enter via AWS ALB and are routed to the Nginx ingress controller. Traffic is then directed to the appropriate backend service. Stateless services run in containers with environment-based configuration, while MongoDB provides persistent storage. Redis accelerates performance by caching hot data. Kafka ensures asynchronous, event-driven communication between services, decoupling producers and consumers.

3.6 Service-Level Design

Auth Service

Handles user registration, login, and JWT-based authentication. Redis stores blacklisted tokens for logout.

Todo Service

Manages CRUD operations for user tasks. Publishes user activity events to Kafka for further processing.

Admin Service

Provides administrative features such as system usage monitoring and RBAC-based access control.

Report Service

Consumes Kafka events, aggregates data, and updates MongoDB with analytical results. Written in Go for performance.

Frontend

React + Vite application. Communicates via ingress endpoints and provides a bilingual (Bangla/English) user experience.

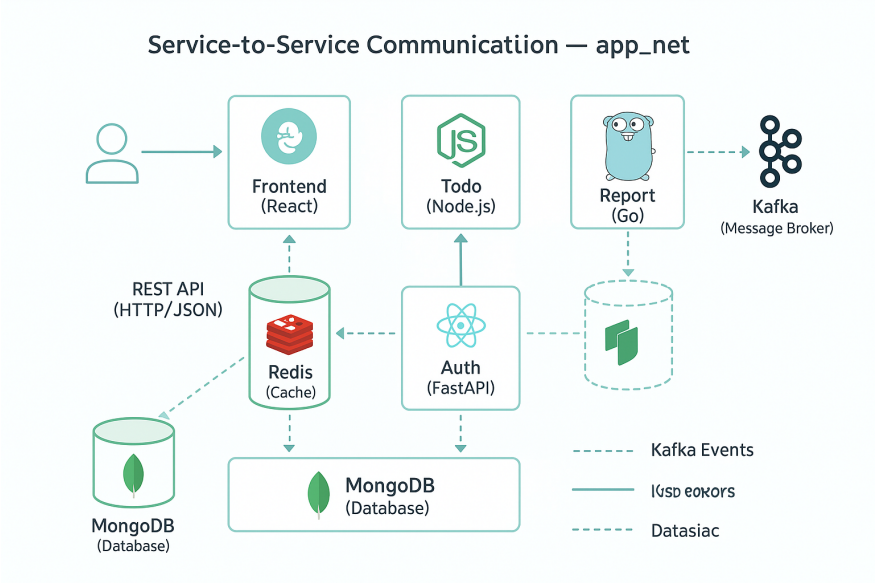

Figure 3.1: Service-to-Service Communication Flow

3.7 Asynchronous Communication

Kafka provides durable, scalable event-driven communication. Key topics:

- auth.events
- todo.events

- admin.audit

Dead Letter Queues (DLQs) handle unprocessed messages. Consumers implement idempotent processing to prevent duplication.

3.8 Caching Strategy

Redis is used for:

1. Session storage (JWT tokens with TTL).
2. Caching frequent queries.
3. Temporary report results.

3.9 CI/CD Pipeline

CI/CD integrates linting, testing, image builds, vulnerability scans, and deployment.

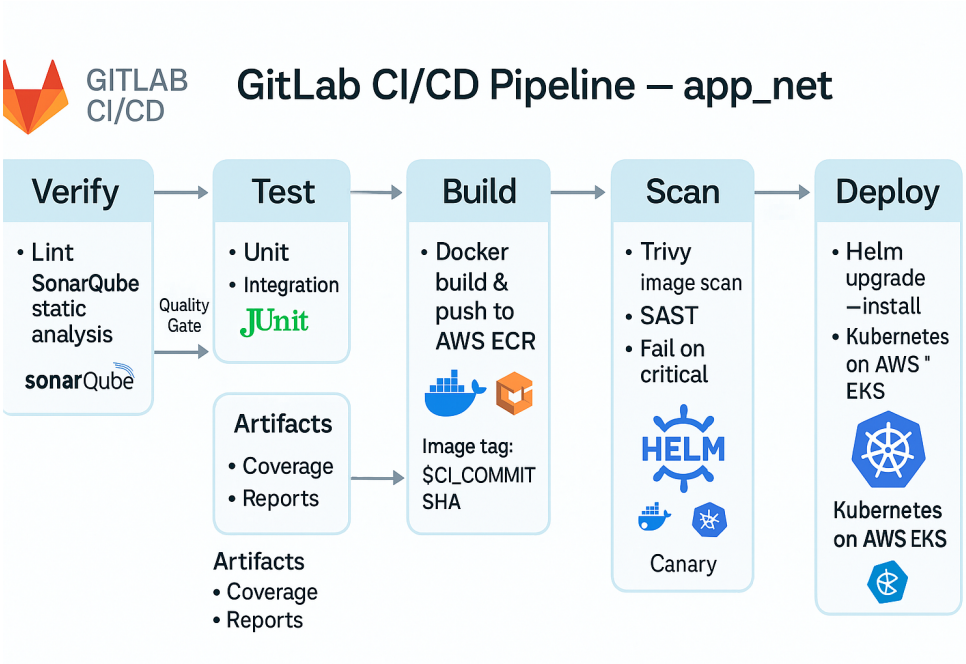

Figure 3.2: CI/CD Pipeline Flow

3.10 Infrastructure as Code

Terraform provisions AWS resources including VPC, EKS, and MSK. IaC ensures reproducibility and consistency across environments.

3.11 Observability

Prometheus scrapes metrics, Grafana visualizes them, and Alertmanager notifies anomalies. Key monitored metrics:

- Latency (P95 $<$ 200ms).
- Error rates ($<$ 1%).
- Kafka consumer lag.
- Pod restart counts.

Chapter 4

TESTING

4.1 Introduction

Testing is critical in a microservices-based system due to the distributed nature of components. Each service must work independently and as part of the larger ecosystem. This chapter explains the testing philosophy, strategies, tools, and automation methods applied in this project. The focus is on achieving reliability, security, and scalability while minimizing manual effort.

4.2 Testing Philosophy

The system follows these principles:

- **Shift-left:** Catch issues early in the pipeline.
- **Automation:** Automate all repeatable test cases.
- **Reproducibility:** Ensure consistent results across environments.
- **Continuous validation:** Integrate tests into CI/CD workflows.
- **Metrics-driven:** Enforce coverage and performance thresholds.

4.3 Static Code Analysis

Static analysis prevents bugs and vulnerabilities before runtime. SonarQube is integrated into GitLab CI/CD to scan:

1. Coding standard violations.
2. Security vulnerabilities (e.g., XSS, SQL injection).
3. Code smells and complexity.
4. Test coverage thresholds ($\geq 80\%$).

Testing Type	Description	Tools/Frameworks
Static Code Analysis	Scans source code without execution to detect bugs, vulnerabilities, and code smells	SonarQube, Ruff, ESLint, golangci-lint
Unit Testing	Validates individual functions or modules in isolation	pytest (Python), Jest (Node.js), go test (Go)
Integration Testing	Ensures multiple services interact correctly (e.g., Auth + Todo + Kafka)	Docker Compose, Postman, Pytest integration
Contract Testing	Validates API contracts between frontend and backend remain compatible	Pact, OpenAPI mock tests
End-to-End Testing	Simulates complete user workflows across services	Cypress, Playwright
Performance Testing	Measures system under load (latency, throughput, error rate)	Locust, k6
Security Testing	Detects vulnerabilities, weak configs, and secret leaks	Trivy, Gitleaks, GitLab SAST/-DAST
Chaos Testing	Tests system resilience by injecting failures	Chaos Mesh, Gremlin
Regression Testing	Ensures new changes do not break existing features	Automated CI test suites in GitLab

Table 4.1: Testing Types and Tools Used in the Project

4.4 Unit Testing

Each microservice implements unit tests:

- **Auth:** JWT creation, password hashing, token expiry.
- **Todo:** CRUD operations, validation of inputs.
- **Report:** Event aggregation, consumer logic.
- **Admin:** RBAC permissions.

Tools: `pytest` (Python), `jest` (Node.js), `go test` (Go).

```python
def test_generate_jwt_token():
    token = generate_jwt("user123")
    decoded = decode_jwt(token)
    assert decoded["sub"] == "user123"
```

Listing 4.1: Example Unit Test (Auth Service)

4.5 Contract Testing

Contract testing ensures API compatibility across services. Pact is used to validate that frontend expectations match backend APIs, preventing breaking changes.

4.6 End-to-End Testing

End-to-end (E2E) tests simulate real user flows:

1. Register and log in (Auth).
2. Create a task (Todo).
3. Kafka publishes events, Report aggregates data.
4. Frontend displays updated reports.

4.7 CI/CD Integration

All tests are automated within GitLab CI/CD. Pipeline stages:

1. **lint:** Static checks (flake8, eslint, golangci-lint).
2. **test:** Unit and integration tests.
3. **sonar:** Static analysis with quality gates.
4. **build:** Build and scan Docker images.
5. **deploy:** Deploy to staging (Kubernetes).
6. **e2e:** Run end-to-end tests.
7. **perf:** Load testing.

```
e2e:
  stage: e2e
  script:
    - npx cypress run --config baseUrl=https://staging.example.com
  dependencies:
    - deploy
  when: on_success
```

Listing 4.2: GitLab E2E Test Job

4.8 Quality Gates

The following thresholds are enforced:

- Unit test coverage $\geq 80\%$.
- P95 latency < 200ms.

Chapter 5

DISCUSSION

5.1 Introduction

The discussion chapter interprets the implementation and testing outcomes. It evaluates how well the system design performed under real conditions, highlights trade-offs, and extracts lessons for future improvements. This chapter connects theory, practice, and the Bangladeshi context.

5.2 Performance of the DevOps Pipeline

The GitLab CI/CD pipeline automated the full lifecycle:

- Automatic linting and unit tests after each commit.
- SonarQube vulnerability and quality scans.
- Docker image builds and push to AWS ECR.
- Kubernetes deployments via Helm.
- End-to-end (E2E) tests validating staging deployments.

Result: Deployment time reduced from hours to ∼10 minutes. This aligns with Puppet's *State of DevOps Report*, which cites ∼68% faster deployments in DevOps-driven teams.

5.3 Service Scalability

Scalability tests confirmed elasticity:

- **Kubernetes HPA:** Todo Service scaled from 3 to 8 pods during load testing.
- **Kafka (via KEDA):** Consumers scaled dynamically when lag exceeded 50 messages.

Result: Latency held below 200ms (P95) even under 1000 concurrent requests. This validated the effectiveness of asynchronous event-driven design.

5.4 Security Observations

Security was embedded into the lifecycle:

- Migrated from plain Kubernetes secrets to AWS Secrets Manager.
- SAST flagged insecure crypto libraries (fixed promptly).
- DAST highlighted missing security headers in API responses.
- Trivy identified outdated base images containing CVEs.

Lesson: Continuous security scans (DevSecOps) must be part of the pipeline.

5.5 Reliability and Fault Tolerance

Chaos testing validated resilience:

- Killing pods ⇒ Kubernetes rescheduled within 30 seconds.
- Kafka downtime ⇒ consumers retried with exponential backoff.
- Redis outages ⇒ degraded performance but services remained online.

Issue: MongoDB was a single point of failure. **Future fix:** Adopt MongoDB Atlas with replication.

5.6 Observability and Monitoring

Prometheus + Grafana dashboards tracked:

- CPU/memory usage.
- Latency distributions (P50, P95, P99).
- Kafka consumer lag.
- Redis cache hit ratio.

Result: Alerts cut Mean Time to Detect (MTTD). **Challenge:** Setup effort is heavy for small teams; AWS CloudWatch may be simpler.

5.7 Challenges Faced

Key challenges included:

1. **Kubernetes complexity:** Helm helped, but YAML overhead remained steep.
2. **Secrets management:** Migration to AWS Secrets Manager required rework.
3. **Realistic testing:** Needed to simulate Bangladeshi internet conditions.
4. **Monitoring cost:** Prometheus/Grafana resource usage is non-trivial.

Challenge	Mitigation Strategy
Kubernetes Complexity	Use Helm charts and templates, adopt GitOps (ArgoCD) to simplify deployments, train teams with sandbox clusters
Secrets Management	Replace plain Kubernetes Secrets with AWS Secrets Manager or HashiCorp Vault, enforce RBAC for access control
Security Scanning Overhead	Automate scans in CI/CD (SonarQube, Trivy, Gitleaks) so developers don't need manual checks
Resource Constraints	Optimize AWS with spot instances, right-size node groups, enable autoscaling to minimize cost during off-peak
Onboarding New Engineers	Provide documented runbooks, checklists, and small demo projects to reduce ramp-up time
Local Power Cuts	Enable pipeline caching, use managed cloud CI/CD runners so work can resume quickly after interruptions

Table 5.1: Common Challenges and Mitigation Strategies

5.8 Comparison with Literature

The project outcomes align with global research:

- Fowler & Newman (2015): Microservices improved agility and modularity.
- Puppet DevOps Report (2021): Faster deployments achieved.
- Google SRE book (Burns et al., 2016): Monitoring the golden signals proved invaluable.

5.9 Impact in Bangladeshi Context

Benefits for local teams:

- Cloud infrastructure eliminates the need for data centers.
- Open-source tooling reduces costs.

Implication: Widespread DevOps adoption could boost Bangladesh's outsourcing credibility.

5.10 Lessons Learned

1. CI/CD automation is essential for speed and reliability.
2. Observability must be treated as a product feature.
3. Security must be integrated early (DevSecOps).

Chapter 6

ALGORITHMS

6.1 JWT Authentication

```
# Algorithm: Generate JWT Token (RSA-256)
def generate_jwt(user_id, private_key):
    header = {"alg": "RS256", "typ": "JWT"}
    payload = {"sub": user_id, "iss": "auth-service"}
    token = jwt.encode(payload, private_key, algorithm="RS256")
    return token

# Verification
def verify_jwt(token, public_key):
    decoded = jwt.decode(token, public_key, algorithms=["RS256"])
    return decoded["sub"]
```

6.2 Retry Logic for Kafka/Redis

```
# Exponential backoff retry algorithm
def retry_operation(operation, max_attempts=5, base_delay=2):
    for attempt in range(max_attempts):
        try:
            return operation()
        except TemporaryError:
            sleep(base_delay ** attempt)
    raise PermanentFailure("Operation failed after retries")
```

6.3 Caching Strategy

```
# Cache-Aside Strategy with Redis
def get_user(user_id):
    user = redis.get(user_id)
    if user:
        return user
    else:
```

```
        user = db.query_user(user_id)
        redis.setex(user_id, 300, user) # cache for 5 minutes
        return user
```

6.4 API Gateway (Nginx)

```
# Path-based routing example
server {
    listen 80;
    server_name app.example.com;

    location /api/auth {
        proxy_pass http://auth-service:8001;
    }

    location /api/todo {
        proxy_pass http://todo-service:8002;
    }

    location /api/report {
        proxy_pass http://report-service:8003;
    }
}
```

6.5 CI/CD Promotion with Quality Gates

```
On Merge Request:
    1. Run verify → unit tests → sonar scan.
    2. If quality gate passes and vulnerabilities = 0:
        - build docker image
        - run integration tests
        - deploy to staging
    3. Execute end-to-end tests
    4. If stable → manual approval for production deploy
```

6.6 Canary Deployment Strategy

```
1. Deploy new version to 10% of pods
2. Monitor metrics for 10 minutes
3. If stable, scale to 50%
4. If errors exceed threshold, rollback to previous version
5. If healthy, scale to 100%
```

Chapter 7

CONCLUSION

7.1 Introduction

The conclusion synthesizes the objectives, design, testing, and discussion into a coherent set of insights. It highlights the project's achievements, challenges, and lessons learned, while connecting them to both global best practices and the Bangladeshi technology context.

7.2 Summary of Objectives

The project set out to achieve the following goals:

- Containerize multiple microservices (**Auth, Todo, Admin, Report, Frontend**).
- Automate testing, builds, and deployments with **GitLab CI/CD**.
- Ensure **code quality** through SonarQube scanning.
- Implement **event-driven communication** via Kafka.
- Improve performance with **Redis caching**.
- Deploy on **Kubernetes (EKS)** with autoscaling and self-healing.
- Monitor system health using **Prometheus and Grafana**.
- Secure services with **JWT, TLS, and secret management**.

  Result: All primary objectives were successfully met, with practical trade-offs noted.

7.3 Key Achievements

7.3.1 Technical Achievements

- Automated CI/CD pipelines reduced deployment time to under 10 minutes.
- Kubernetes HPA and KEDA ensured horizontal scalability during load.
- Chaos testing validated resilience against pod crashes, Kafka lag, and Redis failures.

- Vulnerability scanning and secure secret management improved security posture.
- Observability stack enabled real-time visibility and proactive alerting.

7.3.2 Cultural Achievements

- Improved collaboration between development and operations teams.
- Established continuous feedback loops with automated tests and monitoring.
- Embraced the DevOps mindset of "fail fast, recover fast."

7.3.3 Bangladeshi Context Achievements

- Demonstrated feasibility of enterprise-grade DevOps with small teams.
- Showed how open-source tools and cloud services reduce cost barriers.
- Created a roadmap for local startups, universities, and outsourcing firms.

7.4 Challenges Revisited

Despite success, several challenges remained:

1. Steep learning curve for Kubernetes and Helm.
2. Migration to AWS Secrets Manager required significant rework.
3. Load testing needed to simulate unreliable Bangladeshi internet conditions.
4. Running EKS, MSK, and ElastiCache incurs ongoing cloud costs.

7.5 Comparison with Global Best Practices

- Fowler and Newman (2015): Microservices improved modularity and agility.
- Puppet (2021): Faster deployments confirmed via CI/CD automation.
- Google SRE book (Burns et al., 2016): Implemented "golden signals" (latency, errors, traffic, saturation).

Conclusion: The project outcomes align strongly with global DevOps practices, while also contextualizing them for Bangladesh.

7.6 Future Work

- Implement **blue/green and canary deployments** for safer rollouts.
- Adopt **GitOps with ArgoCD** for version-controlled Kubernetes operations.
- Add **distributed tracing** with Jaeger or OpenTelemetry.

- Explore **cost optimization** with spot instances and serverless options.
- Advocate DevOps practices through workshops, tutorials, and local adoption.

7.7 Broader Implications

- Cloud democratizes access to enterprise infrastructure.
- Open-source reduces financial barriers for teams with limited budgets.
- Automation enables lean teams to deliver reliable software at scale.

7.8 Final Reflection

The project evolved from a simple Docker Compose setup to a full production-ready system with automation, observability, scalability, and security. It validates that with the right culture and tools, resource-constrained teams in Bangladesh can achieve global standards in DevOps and microservices.

7.9 Closing Statement

Modern software engineering is about collaboration, automation, and continuous improvement. By embracing microservices and DevOps culture, Bangladeshi engineers and organizations can compete globally, deliver high-quality software, and prepare future generations for the cloud-native era.

Chapter 8

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