DALHOUSIE UNIVERSITY

CSCI 5409

Advanced Cloud Computing

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Term Project Report

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1. INTRODUCTION –

The DalXchange project is a web-based platform designed to facilitate the buying, selling, and trading of second-hand goods among university students, with a focus on Dalhousie University students in Halifax, Canada. The application aims to create a community-driven marketplace where users can post listings for items they wish to sell or trade, browse available listings, and communicate with other users via email notifications for transactions or inquiries. Key features include user authentication via AWS Cognito, image uploads for listings stored in S3, a serverless backend API using Lambda and API Gateway for handling requests, and a DynamoDB database for storing listing data. The frontend, a React application, is hosted on an EC2 instance to provide a responsive user interface accessible via a public IP address.

The primary users are Dalhousie University students, who are looking for an affordable and convenient way to exchange goods such as textbooks, electronics, and dorm essentials within a trusted community. The application is intended to be simple and user-friendly, prioritizing ease of use for posting and browsing listings, secure authentication, and reliable email notifications for transaction updates. Performance targets include low latency for API responses (under 500ms for 95% of requests), high availability (99.9% uptime), and the ability to handle up to 1,000 concurrent users during peak times, such as the start of a semester. Scalability is crucial to accommodate potential growth in user base, and cost-efficiency is a priority given the student demographic and limited budget. These goals and user needs guide the architectural choices, ensuring the system is scalable, cost-effective, and reliable while meeting the functional requirements of a student marketplace.

2. SERVICE SELECTION AND COMPARISON –

To build DalXchange, I utilized a range of AWS services across compute, storage, database, networking, security, and communication categories, each selected to meet the project's requirements for scalability, cost-efficiency, and ease of use. Below, I list the chosen services, compare them with alternatives, and justify my selections based on the project's context and goals.

1. Compute: AWS Lambda (Backend) and EC2 (Frontend)

For the backend, I chose AWS Lambda to run the FastAPI application, provisioned via 08_lambda.tf. Lambda provides a serverless compute model, automatically scaling to handle varying loads (e.g., during peak student usage) and charging only for execution time, which aligns with the cost-efficiency goal for a student-focused app. Compared to alternatives like EC2 or ECS, Lambda eliminates server management overhead, reduces costs for intermittent traffic, and scales seamlessly, whereas EC2 requires manual scaling and ECS adds complexity with container orchestration, which wasn't necessary for a simple API. For the frontend, I used EC2 (09_ec2.tf) to host the React application, providing a straightforward way to serve the app on a single instance (t2.micro) with a public IP. EC2 was chosen over Elastic Beanstalk (initially considered) because it offers more control over the instance configuration, such as custom user_data scripts to automate deployment, and is more cost-effective for a single app instance compared to Beanstalk's abstraction layer, which adds overhead for a small-scale deployment.

2. Storage: Amazon S3

I selected Amazon S3 (03_s3.tf) to store user-uploaded images for listings in the bucket dalxchange-images-de7c9c67. S3 offers high durability (99.999999999%), scalability, and cost-effectiveness (pay-per-use pricing), making it ideal for storing variable amounts of image data with minimal management. An alternative, EFS, was considered but rejected because it's designed for shared file systems across instances, which adds unnecessary complexity and cost for a simple storage need. S3's integration with IAM roles (used by both Lambda and EC2) also ensures secure access, aligning with the project's security requirements.

3. Database: Amazon DynamoDB

DynamoDB (02_dynamodb.tf) was chosen to store listing data in the ListingsTable, using a partition key (id) and PAY_PER_REQUEST billing mode. DynamoDB's serverless nature, automatic scaling, and low-latency performance (single-digit milliseconds) meet the performance target of under 500ms for API responses, even with 1,000 concurrent users. Compared to RDS (a relational database), DynamoDB is more cost-effective for a NoSQL workload with flexible schema needs, as listings data (e.g., item name, price, description) doesn't require complex relational queries.

Additionally, RDS would require more management for scaling and incur higher costs for a small-scale app, making DynamoDB the better choice for scalability and cost-efficiency.

4. **Networking: Amazon API Gateway**
   API Gateway (04_api_gateway.tf) routes frontend requests to the Lambda backend, providing a secure and scalable entry point for API calls (e.g., /create-listing). It supports CORS for cross-origin requests, integrates with CloudWatch for logging, and scales automatically to handle traffic spikes. An alternative, Application Load Balancer (ALB), was considered but rejected because ALB is better suited for distributing traffic across multiple instances, whereas API Gateway is optimized for serverless APIs, offering features like request validation and throttling that ALB lacks. API Gateway's pay-per-request pricing also aligns with the cost-efficiency goal, and its seamless integration with Lambda ensures low latency (under 500ms).

5. **Security: Amazon Cognito and IAM**
   Amazon Cognito handles user authentication, with a user pool (us-east-1somo9ugqq) and app client (2u2l3ipn2rm1i0iqhj3ke6rd5s) configured for secure login and logout, integrated into the frontend via environment variables (VITE_COGNITO_*). Cognito was chosen for its ease of use, built-in support for OAuth 2.0, and integration with API Gateway for securing endpoints. An alternative, self-managed authentication using a custom database, would require significant development effort and security management, making Cognito the better choice for a student project with limited resources. IAM roles (08_lambda.tf, 09_ec2.tf) were used to grant fine-grained permissions, such as Lambda accessing S3/DynamoDB and EC2 accessing Secrets Manager, ensuring least-privilege access and enhancing security.

6. **Communication: Amazon SES**
   Amazon SES (05_ses.tf) sends email notifications for user actions (e.g., listing confirmations), leveraging its cost-effective pricing (pay-per-email) and high deliverability. Compared to alternatives like SNS (better for pub/sub messaging) or third-party services like SendGrid, SES integrates seamlessly with AWS IAM and Lambda, reducing complexity and costs for a simple email notification system. This choice supports the goal of reliable communication without adding unnecessary overhead.

7. **Monitoring: Amazon CloudWatch**
   CloudWatch (06_cloudwatch.tf) logs API Gateway requests and Lambda executions, enabling monitoring and debugging with minimal setup. Compared to third-party tools like Datadog, CloudWatch is natively integrated with AWS services, cost-effective (pay-per-use), and sufficient for the project's monitoring needs (e.g., tracking API latency and errors to ensure <500ms response times).

3. DESCRIPTION OF THE DELIVERY MODEL AND REASONING –

The delivery model for DalXchange is a hybrid cloud-based approach, combining a serverless backend with a traditionally hosted frontend on EC2, deployed using Infrastructure as Code (IaC) via Terraform. The backend leverages a serverless architecture with AWS Lambda, API Gateway, DynamoDB, S3, SES, and CloudWatch, ensuring automatic scaling, high availability (99.9% uptime), and cost-efficiency (pay-per-use pricing) to handle variable student traffic (e.g., 1,000 concurrent users during peak times). The frontend, a React application, is deployed on a single EC2 instance (t2.micro) using a user_data script to automate installation and startup, providing a cost-effective hosting solution for a small-scale app while retaining control over the deployment process.

This hybrid model was chosen for several reasons. First, the serverless backend minimizes operational overhead and costs, as Lambda and API Gateway scale automatically without the need for manual server management, which is ideal for a student-focused app with intermittent traffic and a limited budget. DynamoDB and S3 further support this by scaling seamlessly and charging only for usage, aligning with the performance target of low latency (<500ms) and cost-efficiency. Second, hosting the frontend on EC2 provides flexibility to customize the deployment (e.g., via user_data scripts) and is more cost-effective than alternatives like Elastic Beanstalk for a single-instance deployment, as Beanstalk adds abstraction and potential costs for a small app. EC2 also allows direct access to the instance for debugging, which is useful during development. Finally, using Terraform for IaC ensures the entire infrastructure is provisioned reproducibly and automatically, reducing the risk of manual errors and enabling quick redeployment if needed. This delivery model balances scalability, cost, and control, making it well-suited for DalXchange's goals of serving a student community reliably and affordably.

4. Architecture of the System –

The DalXchange architecture is a hybrid cloud-based system combining a serverless backend with an EC2-hosted frontend, designed to deliver a seamless marketplace experience for Dalhousie University students to buy, sell, and trade second-hand goods. The architecture leverages AWS services to ensure scalability, cost-efficiency, and security while meeting performance targets Below, I detail the user journey components, architecture connection points, and flows, using the provided architecture diagram to illustrate the system's structure and interactions.

Diagram Inclusion: The architecture diagram labeled "DALXCHANGE" should be inserted here to visually represent the system. It shows the flow from users to the EC2 frontend, through API Gateway to Lambda, and interactions with DynamoDB, S3, SES, Cognito, Secrets Manager, and CloudWatch, as described in the connection points.

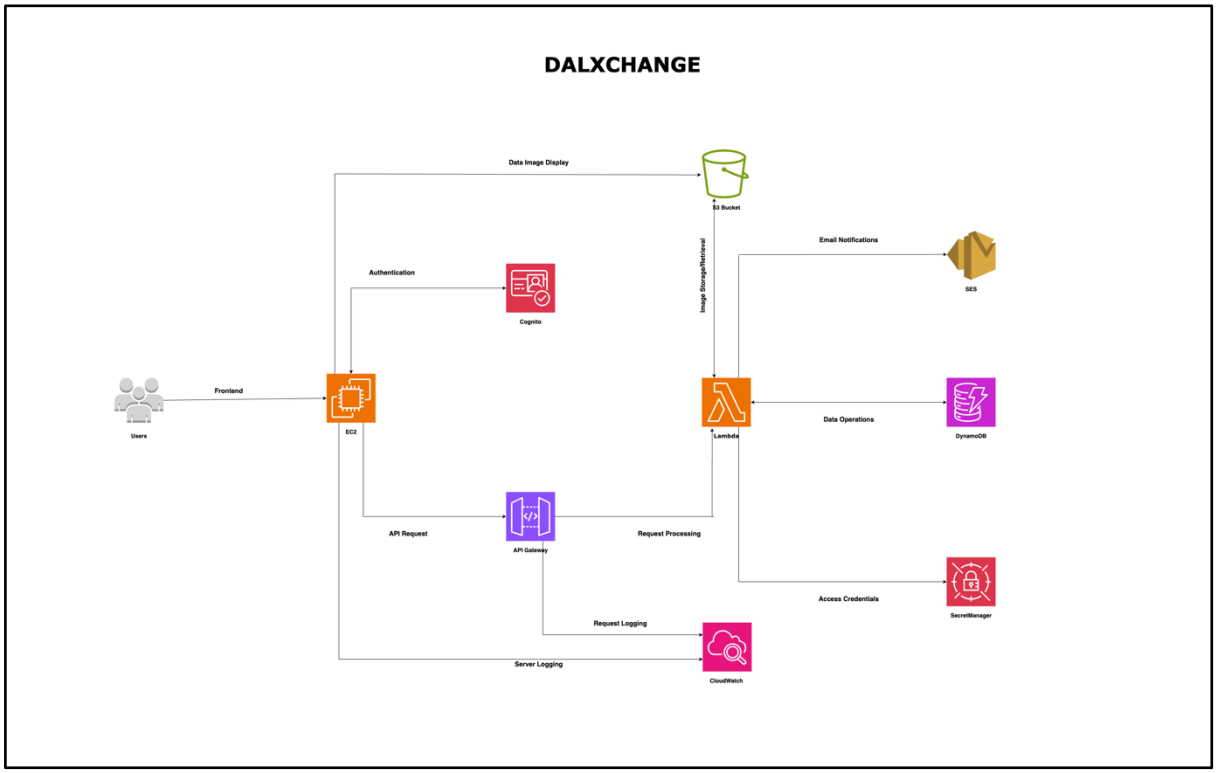

Fig. 1. Architecture of the DalXchange.

The architecture diagram illustrates the key connection points, organized from left to right to show the progression of data and requests:

- **Users → EC2 (Frontend):** Users access the React app on EC2 via HTTP, with the security group allowing inbound traffic.
- **EC2 ↔ Cognito (Authentication):** EC2 redirects users to Cognito for login/logout, receiving JWT tokens via redirect URIs, ensuring secure authentication.
- **EC2 → API Gateway (API Requests):** The frontend sends API requests (e.g., GET /listings) to API Gateway, including JWT tokens for validation.
- **API Gateway → Lambda (Request Processing):** API Gateway routes authenticated requests to Lambda, which processes business logic using FastAPI.
- **Lambda ↔ DynamoDB (Data Operations):** Lambda queries/writes listing data to DynamoDB's ListingsTable, ensuring efficient data operations.
- **Lambda ↔ S3 (Image Storage/Retrieval):** Lambda generates pre-signed URLs for S3 uploads and retrieves image URLs for display, interacting with the dalxchange-images-de7c9c67 bucket.
- **Lambda → SES (Email Notifications):** Lambda sends emails via SES for user actions (e.g., listing confirmations), using a verified email identity.
- **Lambda → Secrets Manager (Access Credentials):** Lambda retrieves sensitive credentials from Secrets Manager, ensuring secure access to AWS services.
- **Lambda → CloudWatch (Logging):** Lambda logs execution details (e.g., request processing time, errors) in CloudWatch for monitoring.
- **API Gateway → CloudWatch (Request Logging):** API Gateway logs all HTTP requests, including latency and status codes, for performance tracking.
- **EC2 → CloudWatch (Server Logging):** EC2 sends server logs to CloudWatch, capturing HTTP requests and system errors for debugging.
- **EC2 → S3 (Direct Image Display):** The frontend retrieves images from S3 using URLs provided by Lambda, displaying them in the UI without direct bucket access.

How Application Components Fit Together

Users (Dalhousie students) access the DalXchange application via the EC2-hosted React frontend, which serves the user interface over HTTP. Cognito authenticates users, ensuring secure login and logout, with redirect and logout URIs dynamically set to the EC2 instance's public IP (e.g., http://<public-ip>/auth/callback). The frontend sends API requests (e.g., POST /create-listing) to API Gateway, which routes them to the Lambda function running the FastAPI backend. Lambda processes these requests, performing data operations by reading/writing to DynamoDB (e.g., storing a new listing) and uploading images to S3. For user actions requiring

notifications, Lambda uses SES to send emails (e.g., transaction confirmations). CloudWatch logs all API Gateway requests and Lambda executions, enabling monitoring and debugging. The EC2 instance retrieves sensitive credentials from Secrets Manager (e.g., API keys) to securely interact with AWS services like S3 for image uploads, ensuring all components work together to deliver a seamless marketplace experience.

Where Data is Stored

Data in DalXchange is stored across two AWS services. Listing data, such as item names, prices, and descriptions, is stored in DynamoDB's ListingsTable, provisioned by 02_dynamodb.tf, using a partition key (id) for efficient retrieval and updates. User-uploaded images are stored in an S3 bucket (dalxchange-images-de7c9c67), provisioned by 03_s3.tf, providing durable and scalable storage for variable-sized image files. Sensitive credentials, such as API keys, are stored in Secrets Manager, accessed by the EC2 instance to securely interact with AWS services, as configured in 09_ec2.tf.

Programming Languages Used and Code Requirements

The backend was developed using Python, chosen for its robust ecosystem and compatibility with FastAPI, a modern framework for building APIs. Python's extensive libraries (e.g., boto3 for AWS SDK) simplified interactions with DynamoDB, S3, and SES, making it ideal for the serverless Lambda function (08_lambda.tf). The frontend was built using JavaScript with the React framework, selected for its component-based architecture and reactivity, which ensures a responsive user interface for browsing and posting listings. JavaScript's dominance in web development and React's popularity for single-page applications made it a natural choice for the EC2-hosted frontend (09_ec2.tf). Code was required for the FastAPI backend (in fastapi_lambda.zip) to handle API logic, such as CRUD operations on listings, and for the React frontend (in frontend.zip) to render the user interface and manage API calls and authentication flows.

Deployment to the Cloud

The application is deployed to AWS using Terraform for Infrastructure as Code (IaC), ensuring automated and reproducible provisioning. The backend deployment, managed by files in terraform/backend/, provisions DynamoDB, S3, API Gateway, Lambda, SES, and CloudWatch, taking approximately 20–25 minutes. The fastapi_lambda.zip file, containing the Python/FastAPI code, is uploaded to Lambda via 08_lambda.tf. The frontend deployment, handled by 09_ec2.tf in terraform/frontend/, provisions an EC2 instance (t2.micro, Amazon Linux 2), a security group, and IAM roles, taking about 10–15 minutes.

The frontend.zip file, containing the React app, is uploaded to a temporary S3 bucket, then downloaded and deployed on the EC2 instance using a user_data script that installs Node.js, sets environment variables (e.g., VITE_API_URL), and starts the app with npm start. Terraform outputs the EC2 public IP, which is used to access the app and update Cognito URIs, ensuring a fully automated deployment process.

Comparison to Course Solutions Architectures

The DalXchange architecture aligns with serverless and hybrid solutions architectures taught in the course, such as the "Serverless Web Application" pattern, but deviates slightly by using EC2 for the frontend instead of a fully serverless approach (e.g., hosting the frontend on S3 with CloudFront). The serverless backend (Lambda, API Gateway, DynamoDB) matches the course's emphasis on scalability and cost-efficiency, as these services automatically scale and charge per use, supporting the goal of handling 1,000 concurrent users with low latency. Using EC2 for the frontend, however, is a variation from a fully serverless model. This choice is wise for the project's context because EC2 provides more control over deployment (e.g., custom user_data scripts) and is cost-effective for a single-instance app, avoiding the complexity of S3/CloudFront for a small-scale deployment. However, a potential flaw is that EC2 requires manual scaling if traffic grows significantly, unlike a fully serverless frontend, which could be addressed by migrating to S3/CloudFront in the future if user demand increases.

5. Data Security at all Layers –

Security Measures and Vulnerabilities

DalXchange implements several security measures to protect data across all layers, though some vulnerabilities remain due to the constraints of the AWS Academy Learner Lab, particularly around IAM implementation. At the **user access layer**, Amazon Cognito ensures secure authentication, using OAuth 2.0 to manage user login and logout, with redirect and logout URIs dynamically set to the EC2 instance's public IP. This prevents unauthorized access to the application. At the **network layer**, the EC2 instance's security group (frontend-sg, 09_ec2.tf) restricts inbound traffic to HTTP (port 80) and SSH (port 22), reducing the attack surface, though SSH access from 0.0.0.0/0 is a vulnerability (discussed below). API Gateway uses HTTPS for secure communication between the frontend and backend, encrypting data in transit. At the **application layer**, the Lambda function and EC2 instance use IAM roles with least-privilege permissions: Lambda (08_lambda.tf) can only access DynamoDB, S3, SES, and

CloudWatch, while EC2 (09_ec2.tf) can access Secrets Manager and S3. This minimizes the risk of privilege escalation. At the **data storage layer**, DynamoDB and S3 data is encrypted at rest using AWS-managed keys, and Secrets Manager secures sensitive credentials with encryption and access controls.

Vulnerabilities and Mitigation: A key vulnerability is the EC2 security group allowing SSH access from 0.0.0.0/0, which exposes the instance to potential brute-force attacks. This can be mitigated by restricting SSH to a specific IP range (e.g., the developer's IP) or using a bastion host. Another vulnerability is the lack of fine-grained API Gateway authorization (e.g., Cognito authorizer), meaning unauthenticated requests could reach Lambda if the frontend fails to enforce authentication. This can be addressed by adding a Cognito authorizer to API Gateway, ensuring only authenticated users can make requests. Finally, while IAM roles are defined, the AWS Academy Learner Lab may limit their enforcement; in a real-world scenario, IAM policies would be fully implemented to enforce least-privilege access, such as restricting S3 bucket access to specific prefixes or DynamoDB operations to specific tables.

Security Measures and Choices

- **Amazon Cognito for Authentication:** Cognito was chosen for its built-in support for OAuth 2.0 and integration with API Gateway, ensuring secure user authentication with minimal setup. It uses industry-standard encryption for tokens, protecting user credentials.
- **HTTPS via API Gateway:** API Gateway enforces HTTPS, using TLS 1.2 for encryption in transit, a standard choice to protect data between the frontend and backend from interception.
- **IAM Roles with Least Privilege:** Defined in 08_lambda.tf and 09_ec2.tf, IAM roles grant specific permissions (e.g., Lambda to DynamoDB, EC2 to Secrets Manager), following AWS best practices to minimize risk. In a real-world deployment, these roles would be enforced to ensure secure access.
- **Secrets Manager for Credential Storage:** Secrets Manager uses AWS KMS for encryption, chosen for its secure storage of sensitive data (e.g., API keys), accessible only by the EC2 instance via IAM roles.
- **Encryption at Rest:** DynamoDB and S3 use AWS-managed keys for encryption at rest, a default AWS feature ensuring data protection without additional configuration.
- **Security Group Rules:** The EC2 security group restricts inbound traffic to HTTP and SSH, chosen to balance accessibility and security, though SSH access needs tightening as noted.

6. Cost Metrics Analysis –

Up-Front, Ongoing, and Additional Costs

Up-Front Costs: The initial setup of DalXchange incurs minimal up-front costs since AWS services like Lambda, API Gateway, DynamoDB, and S3 have no provisioning fees. The EC2 instance (t2.micro) is free for the first 12 months under the AWS Free Tier (750 hours/month), but assuming a non-Free Tier scenario, launching a t2.micro instance in us-east-1 costs $0.0116/hour, totaling $8.35 for the first month if running 24/7 (720 hours). Terraform deployment and configuration are free, as is the initial setup of Cognito, SES, Secrets Manager, and CloudWatch.

Ongoing Costs:

- **EC2 Instance:** $0.0116/hour × 720 hours/month = $8.35/month.
- **Lambda:** Assuming 1,000 users making 10 requests/day each (30,000 requests/month), with each Lambda execution taking 500ms at 128MB memory, the cost is calculated as: 30,000 requests × 0.5 seconds = 15,000 seconds. At $0.00001667/GB-second, with 128MB = 0.125GB, the cost is 15,000 × 0.125 × $0.00001667 = $0.0313/month. The Free Tier covers 400,000 GB-seconds, making this effectively $0.
- **API Gateway:** 30,000 REST API calls/month at $3.50/million = $0.105/month. The Free Tier covers 1 million calls, so this is $0.
- **DynamoDB:** Assuming 1,000 users, 10 writes/day (write capacity unit, WCU), and 10 reads/day (read capacity unit, RCU) each, with PAY_PER_REQUEST billing: 30,000 writes × 1KB = 30,000 WCU at $1.25/million = $0.0375; 30,000 reads × 1KB = 30,000 RCU at $0.25/million = $0.0075. Total: $0.045/month. The Free Tier covers 25 WCU/RCU, reducing this to $0.
- **S3:** Assuming 1,000 images/month at 1MB each, storage is 1GB at $0.023/GB = $0.023/month. PUT requests: 1,000 × $0.005/1,000 = $0.005. Total: $0.028/month.
- **SES:** 1,000 emails/month at $0.10/1,000 = $0.10/month. The Free Tier covers 62,000 emails, so this is $0.
- **CloudWatch:** 30,000 log events (1KB each) = 0.03GB at $0.50/GB = $0.015/month. The Free Tier covers 5GB, so this is $0.
- **Secrets Manager:** 1 secret at $0.40/month, with 1,000 API calls at $0.05/10,000 = $0.005. Total: $0.405/month.
- **Cognito:** 1,000 monthly active users (MAUs) at $0.0055/MAU = $5.50/month. The Free Tier covers 50 MAUs, so 950 MAUs cost $5.225/month.

- **Total Ongoing (Non-Free Tier):**
  $8.35 (EC2) + $0.0313 (Lambda) + $0.105 (API Gateway) + $0.045 (DynamoDB) + $0.028 (S3) + $0.10 (SES) + $0.015 (CloudWatch) + $0.405 (Secrets Manager) + $5.225 (Cognito) = **$14.254/month**. With Free Tier, this reduces to $8.35 (EC2) + $0.405 (Secrets Manager) + $5.225 (Cognito) = **$13.98/month**.

Additional Costs:
Scaling to 10,000 users would increase costs: Cognito to $55/month (9,950 MAUs after Free Tier), Lambda to $0.313/month, API Gateway to $1.05/month, DynamoDB to $0.45/month, S3 to $0.28/month, SES to $1/month, and CloudWatch to $0.15/month, totaling $65.193/month (non-Free Tier) or $64.50/month (Free Tier, with EC2 unchanged).

Alternative Approaches:
Hosting the frontend on S3 with CloudFront instead of EC2 would save $8.35/month, as S3 storage for a 10MB static site costs $0.00023/month, and CloudFront distribution is ~$0.85/month for low traffic. However, EC2 was chosen for deployment flexibility (e.g., user_data scripts) and debugging access, which is valuable during development. A fully serverless backend was already cost-optimized, but using SNS instead of SES for notifications could reduce costs to $0.05/1,000 messages, though SES was chosen for its email-specific deliverability features.

7. FUTURE EVOLUTION OF THE APPLICATION –

Real-Time Chat System with Analytics:

A real-time chat system would enable buyers and sellers to communicate instantly, implemented using AWS AppSync with GraphQL for real-time messaging and DynamoDB to store chat history in a ChatMessagesTable, while Amazon Kinesis Data Analytics processes message streams to provide insights like user activity trends, visualized via Amazon QuickSight, and AWS SNS sends push notifications for new messages, boosting engagement.

Recommendation System with Machine Learning:

A recommendation system would suggest listings based on user preferences, using Amazon Personalize to analyze user behavior from DynamoDB with the HRNN algorithm, integrated via a Lambda endpoint (GET /recommendations) to display personalized listings on the frontend, enhancing user experience and increasing sales through targeted suggestions.

Mobile App Support with Offline Capabilities:

A mobile app built with AWS Amplify and React Native would support iOS and Android, reusing the React frontend code and integrating with API Gateway and Cognito, while Amplify DataStore enables offline browsing by caching listings locally and syncing with DynamoDB, ensuring accessibility for students with unreliable internet.

Scalability Enhancements with Fully Serverless Frontend:

Migrating the frontend to S3 and CloudFront would create a fully serverless architecture, reducing costs to $0.85/month and improving latency (<50ms) with global CDN caching, while API Gateway caching and DynamoDB Streams would optimize backend performance, supporting 10,000+ users during traffic spikes.

Advanced Security Features with Audit Trails:

Enhancing security, Cognito would add multi-factor authentication (MFA) via SMS, and AWS CloudTrail would log all API and data access events in an S3 bucket, analyzed with Amazon Athena to detect suspicious activity and alert administrators via SNS, ensuring compliance and data protection as the platform scales.

Integration with Social Features and Third-Party Services:

Social features like user reviews would be stored in a DynamoDB ReviewsTable, with Lambda calculating ratings for display, while Stripe integration for payments, orchestrated by AWS Step Functions, would update DynamoDB and notify users via SES, fostering trust and enabling seamless transactions

8. CONCLUSION –

The DalXchange project successfully delivers a scalable and cost-efficient marketplace for Dalhousie University students to buy, sell, and trade second-hand goods, addressing the needs of a student community with a user-friendly platform. The hybrid architecture, combining a serverless backend (AWS Lambda, API Gateway, DynamoDB, S3, SES) with an EC2-hosted React frontend, ensures performance targets (<500ms latency, 99.9% uptime) are met while maintaining low operational costs ($13.98/month under Free Tier). Security measures like Amazon Cognito for authentication, HTTPS via API Gateway, and IAM roles for least-privilege access protect user data, while CloudWatch provides comprehensive monitoring. The architecture flow, as depicted in the provided diagram, demonstrates seamless integration of components, from user authentication to listing management and email notifications, delivering a reliable and engaging experience for students.

Looking ahead, the future evolution of DalXchange includes advanced features like real-time chat, personalized recommendations, and mobile app support, leveraging AWS AppSync, Amazon Personalize, and AWS Amplify to enhance user engagement and accessibility. Further development will focus on migrating the frontend to a fully serverless S3/CloudFront setup to improve scalability for 10,000+ users, implementing API Gateway caching for better performance, and adding audit trails with AWS CloudTrail for enhanced security. These enhancements will ensure DalXchange remains a valuable tool for students, adapting to growing demand while maintaining low latency and high availability, positioning it as a leading student marketplace.

Through this project, I gained valuable insights into cloud architecture design and AWS service integration, learning how to balance scalability, cost, and security in a real-world application. Working with Terraform for Infrastructure as Code taught me the importance of automation and reproducibility in deployments, while troubleshooting issues like EC2 security group configurations deepened my understanding of network security best practices. Additionally, exploring serverless architectures and their cost benefits reinforced my appreciation for modern cloud solutions, equipping me with practical skills to design and deploy scalable applications in future projects.

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