Shopping Lists on Cloud

Large Scale Distributed Systems

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Project Context and Overview

- **Local-First Approach**: Focuses on running code **directly on users' devices** to store data, allowing the app to function even **without an internet connection**. This improves the user experience by letting users **view** and **update** their **shopping lists offline**.
- **Shared Shopping Lists**: Every **shopping list** is assigned a **unique ID**, making **collaboration** easy. Users who have the **list ID** can **work together**, managing and updating items **in real-time**.

Technologies

The application was developed with an emphasis on **clarity, independence** and **accessibility**, leveraging **lightweight** and **reliable technologies** to simplify ongoing usage. The core components include:

- **Frontend: React** (TypeScript), **Tailwind CSS**
- **Backend: Node.js**, **Express.js**
- **Database: SQLite** (server), **IndexedDB** (client)

To enable **scalable communication** between system components and to preserve **consistency** in **distributed environments**, the following technologies were incorporated:

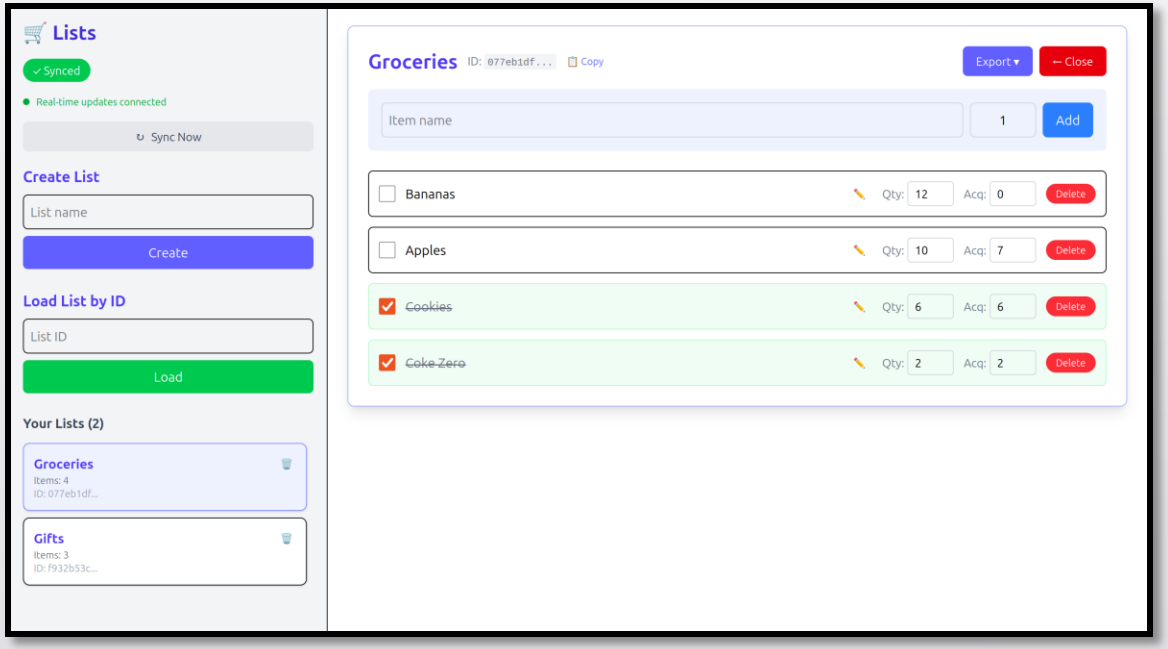
- **Sync & Communication: REST API, Server-Sent Events** (SSE), **UUID** to ensure globally unique identification across the system and **ZeroMQ** for server-to-server gossip and for efficient asynchronous message exchange
- **CRDTs:** Custom TypeScript implementations (**PNCounter**, **LWWRegister**, **AWORSet**, **VectorClock**)

User Interface

- **Modern**, **intuitive** and **responsive UI**, built with React + Tailwind CSS, and capable of executing the **CRUD operations** required for the project:

Features:

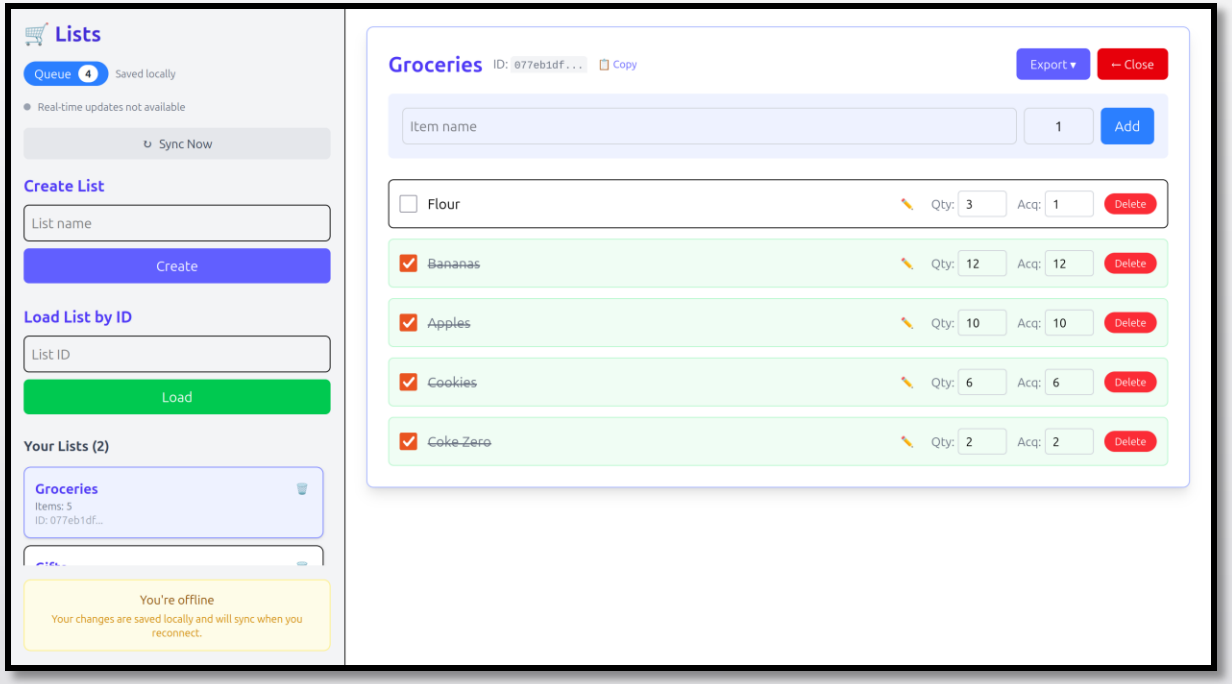
- **Shopping Lists:** create, delete, load and export;
- **Items:** add, delete, rename and check/uncheck;
- Real-time updates via **SSE**;
- **Offline Support** and **Automatic Sync**



Local-First

The client application is designed with a **local-first approach**:

- All changes are immediately applied to **local IndexedDB** for **instant feedback** and **offline support**.
- Changes are **queued** and **synchronized** with the **server** when **connectivity is available**.
- **SyncService** manages **conflict resolution** and **merging** using **CRDT logic**, ensuring a smooth user experience regardless of network state.



CRDTs

We implemented CRDTs (Conflict-free Replicated Data Types) to maintain consistency and correctness in a distributed environment without requiring centralized coordination, ensuring safe merging of concurrent changes. The main CRDT implementations were:

- **AWOR-Set (Add-Wins Observed-Remove Set):** to handle item addition and removal, ensuring that concurrent additions are preserved even in the presence of removals;
- **PN-Counter:** to manage item quantities, allowing both increments and decrements while maintaining convergence across replicas;
- **LWW-Set (Last-Writer-Wins Set):** to store and resolve updates to item names, ensuring that the most recent update is consistently applied.

Cloud

Implemented using the **ZeroMQ** library, the system utilizes **REQ/REP sockets** along with the **Lazy Pirate** pattern to create a robust **request-reply** messaging layer. **Communication follows** this flow:

- **Client → Storage Node (HTTP API) –** CRUD operations on lists/items.
- **Storage Node → Neighbors (ZeroMQ) –** Gossip protocol for replication & hinted handoff.
- **Storage Node → Coordinator (ZeroMQ) –** Forward updates for real-time broadcasting.
- **Coordinator → Clients (SSE) –** Push live updates to all connected frontends.

Cloud

- **Dynamic Connection Handling:** Connections automatically adjust between clients and servers based on availability through **consistent hashing** failover and **quorum-based read/write** adaptation, providing greater flexibility and efficiency.
- **Automated Server Recovery:** Servers recover independently after failures through **deterministic ring rejoining (consistent hashing)** and **hinted handoff** delivery coordinated with **quorum operations**, improving overall system reliability.
- **Seamless Client Interaction:** Users work effortlessly without needing cloud infrastructure knowledge, thanks to **consistent hashing** that automatically routes requests to the correct **replicas** and **quorum operations** that ensure **data availability**.

Main difficulties

- Consistency across clients when there are many concurrent changes;
- The late implementation of the quorum created problems with the lists each customer had access to, and with the synchronization between clients;
- Item check consistency between the check via checkbox and check via quantity and acquired update (merge difficulties).

References

- IndexedDB
- React
- ExpressJS
- UUID
- Local-First
- CRDTs
- ZeroMQ
- Dynamo