URL Shortener with Click Analytics (Multi-Region)

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1.Introduction

Today's digital world, long and complicated URLs often create small inconveniences in marketing and everyday sharing. They don't look clean, can lower click-through rates, and are sometimes difficult to use on social platforms. URL shorteners help solve this by turning long links into simple and easy-to-share versions.

Over time, these tools have grown from basic redirect services into useful systems that also provide helpful information about user interactions. Modern URL shorteners can show details like where the user clicked from, what device they used, and how often the link was accessed. This makes them useful for teams that want to understand their audience better.

This project aims to build a **Multi-Region URL Shortener with Click Analytics** that supports:

- Fast global redirection (target: < 50 ms, 95th percentile)
- High availability (99.99% uptime)
- Scalable click analytics for marketing and growth teams

The system is designed to handle sudden spikes in traffic as well, such as when a link becomes popular or goes viral.

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2. Why This Problem Matters

Whenever links are shared online—whether for promotions, product launches, surveys, or announcements—long URLs often create more trouble than expected. They look cluttered, can break when shared across platforms, and sometimes make users hesitate before clicking. For businesses trying to reach the right audience, this small issue can impact overall engagement.

During discussions with people working in different digital roles, one thing became very clear: teams now need tools that give them clarity about their traffic. Knowing where users come from, how they interact, and what platforms drive clicks helps companies plan better and avoid unnecessary spending.

Because of this shift, modern link-shortening tools are expected to do much more than shorten URLs. A practical and reliable system should:

- Ensure the redirection experience is smooth and quick
- Collect useful information about link usage
- Allow developers to programmatically create and manage short links
- Support global users without delays
- Recognize harmful or misleading URLs before they spread

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3. Stakeholder Analysis

Marketing & Growth Teams: Need clear information about where clicks come from and how campaigns perform.
Developers & Integrators: Need easy and secure APIs to create and manage short links.
Visitors / End Users: Need fast and reliable redirection.
BI / Analytics Teams: Need organized data and reports for analysis and decision-making.
Security & Compliance Teams: Need tools to detect and prevent malicious or unsafe links.

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4. Requirements Specification

4.1 Functional Requirements

The system should be able to:
- Generate short URLs, with an option to set expiry dates.
- Redirect users using the short ID quickly and correctly.
- Record basic click information such as time, device type, location, and referrer.
- Provide an analytics interface and an API for viewing reports.
- Allow administrators to block harmful links or suspicious domains.

4.2 Non-Functional Requirements

Requirement	Target
Availability	99.99% uptime
Redirection Speed	Under 50 ms for most users
Throughput	Handle 100,000+ redirects every second
Security	TLS encryption, OAuth2/JWT, and misuse detection
Data Consistency	Strong consistency for redirects, eventual consistency for analytics
Maintainability	Should be easy to update and extend, following a microservices design

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5. Constraints & Assumptions

• Click analytics may have a slight delay, as data is processed asynchronously.
• Caching with Redis and CDN is assumed to help reduce database load and speed up redirection.
• Users are expected to be routed to the nearest server using Anycast or Geo-DNS.
• Traffic will include both human users and automated bots, so detecting misuse or fraudulent activity is necessary.

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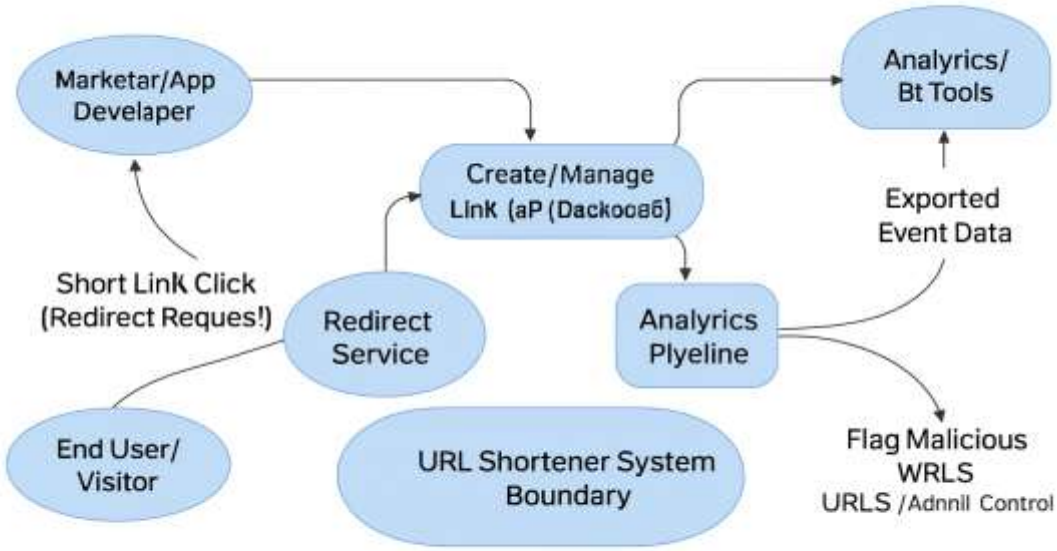
6. System Context Diagram



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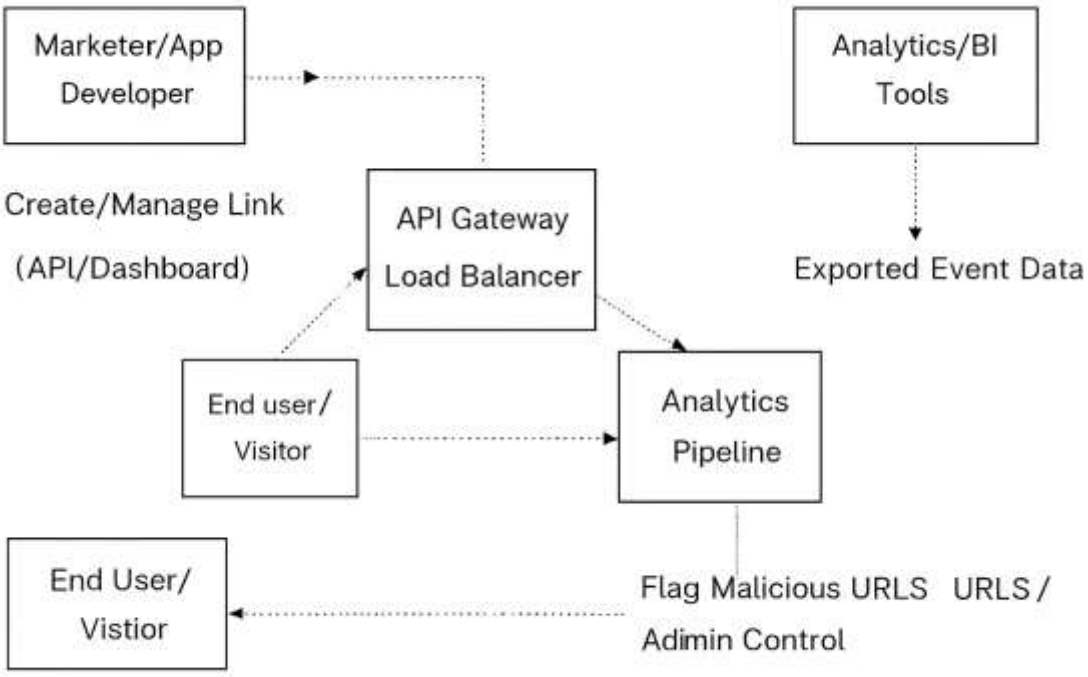
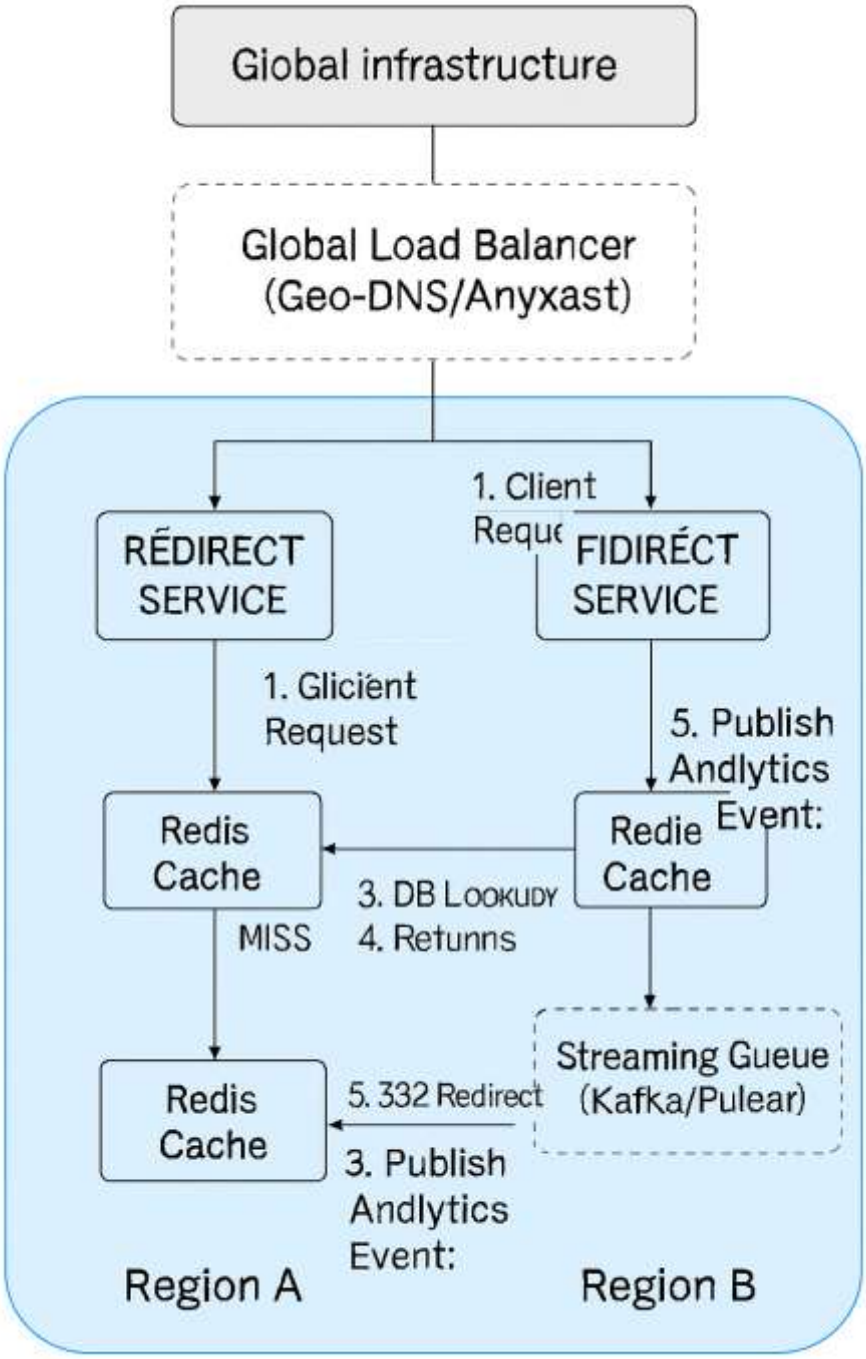
7. Use Case Diagram

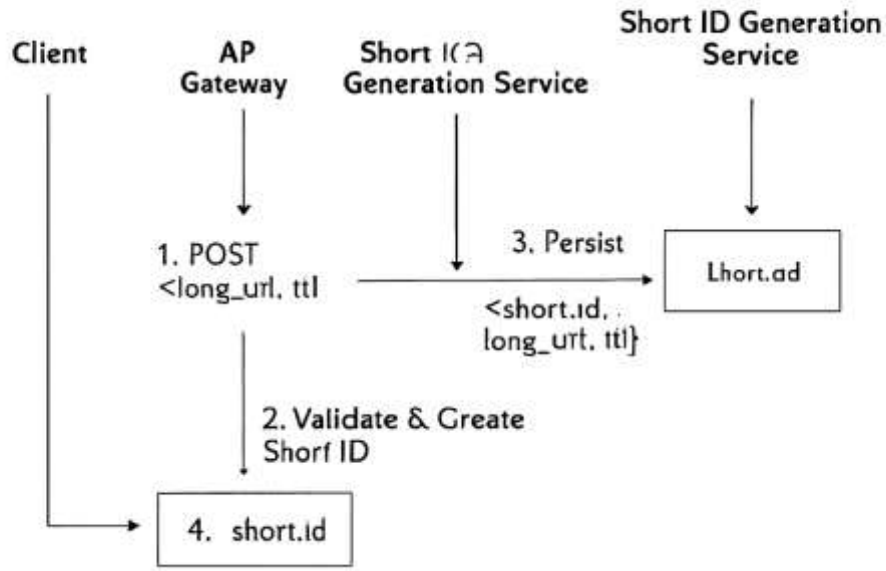


8. High-Level Architecture

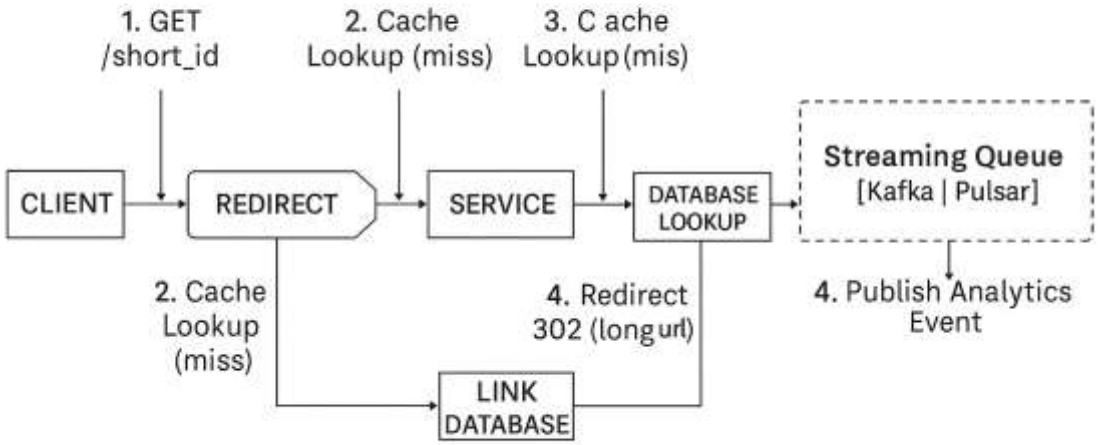


9. Sequence Diagrams

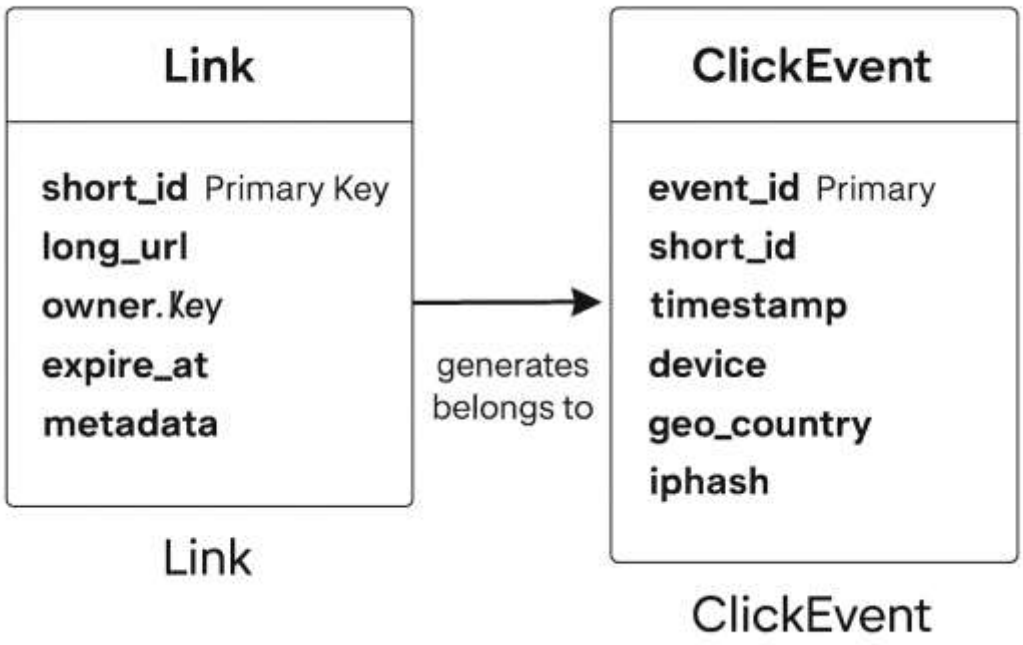
9.1 Create Short Link Workflow



9.2 Redirect + Analytics Event Workflow



10.Data Model (ER Diagram)



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11. Caching, CDN, and Performance Strategy

To achieve global redirection latency under 50ms, the system emphasizes aggressive caching:

1. **Edge Delivery via CDN:** Requests are routed to the nearest CDN edge, minimizing round-trip time for users worldwide.
2. **In-Memory Caching:** High-speed stores like Redis or in-process memory are used to serve link lookups in sub-millisecond time.
3. **Cache Management:** Automatic expiration (TTL) and event-driven updates keep cached data fresh and consistent.
4. **Fallback to Persistent Storage:** Cache misses are efficiently resolved by querying the main link database.

Performance Goal: Maintain a cache hit rate of 95% or higher to ensure consistently fast responses.

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12. Analytics Architecture

- Click events captured at the edge without blocking redirects.
- Streamed via Kafka, Pulsar, or Kinesis for high throughput.
- Aggregated and enriched with metrics and geo-data.

- Stored in OLAP systems like ClickHouse, BigQuery, or Snowflake.
- Exposed via dashboards/APIs for scalable reporting.

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13. Global Deployment & Failover

- Deployed across multiple geographic regions.
- Geo-DNS / Anycast routes users to the nearest instance.
- Active-active replication of link databases across regions.
- Asynchronous replication of analytics streams.
- Automatic failover ensures uninterrupted redirects.

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14. Sample API Endpoints

- **POST /link/create** – Generate a new short link
- **GET /{short_id}** – Redirect to the original URL
- **GET /stats/{short_id}** – Fetch click analytics summary
- **POST /admin/ban** – Block malicious links or domains

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15. Quality of Service & SLOs

- **Redirect Uptime:** 99.99%
- **Redirect Latency:** <50ms (p95)
- **Analytics Delay:** <60 seconds
- **Cache Hit Ratio:** >95%

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16. Security & Abuse Prevention

- Blacklist suspicious domains and keywords
- Detect and throttle bots automatically
- TLS encryption for all endpoints
- OAuth2/JWT authentication for secured APIs

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17. Trade-Off Analysis

Approach	Benefit	Limitation
Event-Driven Analytics	Scales easily and efficiently	Analytics are near real-time, not instant
Multi-Region Deployment	Low latency globally, high availability	Increased infrastructure complexity
Cache-First Reads	Extremely fast redirects	Requires careful cache synchronization
Strongly Consistent Link Store	Ensures accurate redirections	Higher write complexity and overhead

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18. Conclusion

This design outlines a high-performance, globally available URL shortener with integrated click analytics. Leveraging CDN caching, in-memory lookups, and asynchronous analytics, it delivers sub-50ms redirects and scalable reporting for billions of events. Strong consistency guarantees accurate link resolution, while eventual consistency supports large-scale analytics. Inspired by platforms like Bitly, Rebrandly, and Firebase Dynamic Links, this architecture is suited for enterprise-grade marketing and tracking applications.