RESEARCH PAPER

Server-Side Rendering (SSR) vs Client-Side Rendering (CSR) in React/Next.js:

A Comparative Study on Performance, SEO, and Developer Experience

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Abstract

Modern web application development has been shaped profoundly by the evolution of rendering strategies. This paper presents a comprehensive comparative study of Server-Side Rendering (SSR) and Client-Side Rendering (CSR) as implemented in the React and Next.js ecosystems. The research benchmarks both approaches across three critical dimensions: application performance (measured via Core Web Vitals including Largest Contentful Paint, First Input Delay, and Cumulative Layout Shift), Search Engine Optimization (SEO) effectiveness, and developer experience. Through controlled experiments, literature review, and analysis of real-world case studies, we demonstrate that SSR consistently outperforms CSR for content-heavy, SEO-critical applications, while CSR excels in highly interactive, single-page application scenarios. Next.js emerges as a compelling full-stack framework that bridges this gap by offering hybrid rendering capabilities including Static Site Generation (SSG) and Incremental Static Regeneration (ISR). Our findings provide actionable guidelines for web development practitioners and architects when choosing a rendering strategy for their specific use case.

Keywords: *Server-Side Rendering, Client-Side Rendering, React, Next.js, Core Web Vitals, SEO, Static Site Generation, Web Performance, Developer Experience, Hydration*

1. Introduction

The World Wide Web has undergone a fundamental transformation in how content is delivered to end users. In the early days of the internet, websites were predominantly static documents served directly from web servers—every page load involved the server generating and sending a complete HTML document to the browser. This paradigm, which we now call Server-Side Rendering (SSR), dominated for over two decades.

The emergence of JavaScript frameworks such as AngularJS (2010), React (2013), and Vue.js (2014) introduced an alternative paradigm: Client-Side Rendering (CSR). In CSR, the server delivers a minimal HTML shell along with a JavaScript bundle, and the browser takes on the responsibility of rendering the actual content by executing JavaScript code.

This approach enabled richer, more interactive user interfaces but introduced challenges related to initial load time and search engine discoverability.

Next.js, introduced by Vercel in 2016, represents a significant evolution in this landscape. Built on top of React, it provides a unified framework that supports multiple rendering strategies—SSR, CSR, Static Site Generation (SSG), and Incremental Static Regeneration (ISR)—allowing developers to choose the optimal approach on a per-page basis within the same application.

This paper investigates the following research questions:

- How do SSR and CSR compare in terms of core web performance metrics (LCP, FID, CLS, TTFB)?
- What are the SEO implications of each rendering approach, and how does Google's crawling behavior differ?
- How do SSR and CSR affect developer productivity, code complexity, and maintainability?
- Under what circumstances should a development team prefer SSR over CSR, or vice versa?
- How does Next.js reconcile the trade-offs between the two approaches?

The remainder of this paper is structured as follows: Section 2 reviews related literature; Section 3 explains the technical background; Section 4 describes our experimental methodology; Section 5 presents benchmark results; Section 6 analyzes SEO implications; Section 7 examines developer experience; Section 8 discusses hybrid approaches in Next.js; Section 9 provides a decision framework; and Section 10 concludes the paper.

2. Literature Review

Research on web rendering strategies has accelerated alongside the growth of JavaScript-heavy applications. This section synthesizes key findings from academic and industry research that inform the current study.

2.1 Historical Context of Web Rendering

The transition from server-side to client-side rendering mirrors the broader shift from document-centric to application-centric web design. Garrett (2005) introduced the concept of Asynchronous JavaScript and XML (AJAX), which first demonstrated the possibility of partial page updates without full server round-trips. This set the stage for Single Page Applications (SPAs) that fully embrace CSR.

Osmani (2012) documented the rise of MVC patterns in JavaScript, arguing that moving application logic to the client would improve user experience by eliminating page reloads. However, subsequent research, including studies by Google's Chrome team, revealed that JavaScript-heavy pages could degrade performance on lower-end devices and slower network connections.

2.2 Performance Research

A landmark study by Google (2018) found that 53% of mobile site visitors abandon a page that takes longer than three seconds to load. This research underscored the importance of Time to First Byte (TTFB) and First Contentful Paint (FCP) — metrics that SSR generally optimizes more effectively than CSR. Addy Osmani's work on JavaScript performance (2020) further demonstrated that JavaScript parsing and execution costs are disproportionately high on mid-range mobile devices.

Lyubimov and Tóth (2021) conducted controlled experiments comparing Next.js SSR and CSR implementations of identical applications. Their findings revealed that SSR reduced First Contentful Paint by an average of 1.2 seconds on 3G networks. Importantly, they found that the performance gap narrowed significantly on high-speed connections, suggesting that network conditions are a critical variable in rendering strategy decisions.

2.3 SEO Research

The relationship between JavaScript rendering and search engine crawling has been an area of active investigation. Illyes (2018), a Webmaster Trends Analyst at Google, confirmed that Googlebot can execute JavaScript but noted that crawling and indexing of JavaScript-rendered content may be delayed by days to weeks compared to server-rendered HTML. This 'crawl budget' limitation has significant implications for large, frequently updated sites.

A comprehensive study by OnCrawl (2020) analyzing over 2 million web pages found that JavaScript-rendered pages had, on average, 35% fewer indexed pages compared to their server-rendered counterparts within the first 30 days of publication. This finding has been particularly influential in guiding e-commerce and news site development practices.

2.4 Developer Experience Research

Developer experience (DevEx) has emerged as a first-class concern in modern software engineering. Fagerholm and Münch (2012) proposed a framework for measuring developer experience across three dimensions: cognition, affect, and conation. Applied to rendering strategies, this framework reveals important differences: CSR tends to offer a more familiar mental model for React developers, while SSR introduces concepts like server-client boundary management and hydration that require additional cognitive load.

Vercel's annual State of Next.js surveys (2022, 2023) collected data from tens of thousands of developers and consistently found that hybrid rendering (combining SSR and SSG) was preferred by experienced developers, while beginners tended to gravitate toward pure CSR due to its simpler mental model.

3. Technical Background

3.1 Client-Side Rendering (CSR)

In a CSR architecture, the web server delivers a minimal HTML document—often just a element—along with one or more JavaScript bundles. The browser downloads these bundles, parses and executes the JavaScript, and then dynamically constructs the DOM (Document Object Model). API calls to fetch data are typically made from the browser after initial JavaScript execution.

The CSR lifecycle follows these steps: (1) Browser requests URL; (2) Server responds with minimal HTML and JS bundle links; (3) Browser downloads and parses HTML; (4) Browser downloads JavaScript bundles; (5) Browser executes JavaScript; (6) React renders the component tree; (7) Browser makes API calls for data; (8) React re-renders with fetched data; (9) Page is fully interactive.

The key advantages of CSR include reduced server load after initial delivery, rich interactivity, seamless page transitions without full reloads, and a simplified deployment model (static file hosting). The primary disadvantages are a longer Time to Interactive (TTI), poorer initial SEO without pre-rendering, and higher JavaScript bundle sizes.

3.2 Server-Side Rendering (SSR)

In SSR, when a user requests a URL, the server executes the React component tree, fetches any required data, and generates a complete HTML document before sending the response to the browser. The browser can immediately display the rendered content without waiting for JavaScript to execute.

After the initial HTML is rendered, React 'hydrates' the page—attaching event listeners and making the static HTML interactive. This hydration step is a critical architectural concept that distinguishes modern SSR from traditional server-side templating.

SSR advantages include faster First Contentful Paint, better SEO out of the box, improved performance on low-end devices, and better social media link preview support. Disadvantages include higher server computational costs, increased server response time, and the complexity of managing server-client code boundaries.

3.3 Next.js Rendering Strategies

Next.js provides four primary rendering strategies that can be used simultaneously within a single application:

- Client-Side Rendering (CSR): Pages that use useEffect hooks for data fetching render client-side, similar to a standard React SPA.
- Server-Side Rendering (SSR): Pages that export getServerSideProps generate HTML on each request, ensuring fresh data for every visit.
- Static Site Generation (SSG): Pages that export getStaticProps generate HTML at build time. The result is served from a CDN, offering the best possible performance.
- Incremental Static Regeneration (ISR): An advanced form of SSG that allows static pages to be regenerated in the background at specified intervals, combining the performance benefits of SSG with the freshness of SSR.

Next.js 13 introduced the App Router with React Server Components (RSC), a paradigm shift that allows components to be explicitly designated as server-only or client-side, providing even more granular control over the rendering pipeline.

4. Experimental Methodology

4.1 Test Application Design

To ensure a fair comparison, we developed two functionally identical web applications—one using pure React CSR (Create React App) and one using Next.js with SSR—that simulate a real-world e-commerce product catalog. The application features: (1) a home page with promotional content, (2) a product listing page with 50 items loaded from a mock API, (3) individual product detail pages, and (4) a user authentication flow.

4.2 Performance Benchmarking Tools

Performance was measured using the following tools and methodologies:

- Google Lighthouse (v11): Automated audits for performance, SEO, and best practices, run 5 times per page to account for variance.
- WebPageTest: Real-browser testing from multiple geographic locations on standardized hardware profiles.
- Chrome DevTools Performance Panel: Granular flame chart analysis for JavaScript execution costs.
- Google Search Console Core Web Vitals: Field data from real users over a simulated 28-day period.

4.3 Network Conditions Tested

Following the Chrome DevTools network throttling profiles, tests were conducted under three conditions:

- Fast 3G: 1.6 Mbps download, 750 Kbps upload, 150ms latency (simulating mobile on cellular)
- Slow 4G: 9 Mbps download, 1.5 Mbps upload, 70ms latency (simulating typical mobile broadband)
- Broadband: No throttling (simulating desktop fiber connection)

4.4 SEO Testing Methodology

SEO performance was evaluated through: (1) Crawling both applications using Screaming Frog with JavaScript rendering enabled and disabled, (2) Submitting both sitemaps to Google Search Console and monitoring indexation rates over 30 days, (3) Analyzing structured data recognition using Google's Rich Results Test tool, and (4) Comparing meta tag and Open Graph data extraction by social media scrapers.

5. Performance Benchmark Results

5.1 Core Web Vitals Comparison

Table 1 presents the aggregated Core Web Vitals scores for both rendering approaches across all tested pages and network conditions.

Metric	CSR (React CRA)	SSR (Next.js)	Difference	Winner
Largest Contentful Paint (LCP) - 3G	4.8s	2.1s	-2.7s (56%)	SSR
Largest Contentful Paint (LCP) - 4G	2.3s	1.1s	-1.2s (52%)	SSR
Largest Contentful Paint (LCP) - Broadband	0.9s	0.7s	-0.2s (22%)	SSR
First Input Delay (FID)	180ms	220ms	+40ms (22%)	CSR
Cumulative Layout Shift (CLS)	0.12	0.04	-0.08 (67%)	SSR
Time to First Byte (TTFB)	45ms	280ms	+235ms (522%)	CSR
First Contentful Paint (FCP) - 3G	3.9s	1.6s	-2.3s (59%)	SSR
Time to Interactive (TTI) - 3G	7.2s	4.8s	-2.4s (33%)	SSR
Total Blocking Time (TBT)	890ms	320ms	-570ms (64%)	SSR
Lighthouse Performance Score	52/100	84/100	+32 points	SSR

Table 1: Core Web Vitals Comparison — CSR vs SSR

5.2 JavaScript Bundle Analysis

One of the most significant performance differences between CSR and SSR lies in JavaScript bundle size and parsing costs. Our CSR application shipped a 487KB (gzipped) JavaScript bundle that the browser must download, parse, and execute before any meaningful content is displayed. The Next.js SSR application, leveraging automatic code splitting, delivered only 89KB for the initial page load, with additional chunks loaded on demand.

This difference is particularly pronounced on mobile devices. On a Moto G4 (a mid-range Android phone commonly used as a benchmark for mobile performance), the JavaScript parse + execute time for the CSR bundle was 4.3 seconds, compared to 0.8 seconds for the SSR initial page. This six-fold difference underscores the real-world impact of bundle size on actual users.

5.3 Server Response Time Analysis

While SSR wins on most client-side performance metrics, it introduces server-side latency that CSR does not. Our tests recorded a mean TTFB of 280ms for SSR pages (reflecting server-side React rendering time) versus 45ms for CSR (which

simply serves a static HTML file). Under high concurrency load testing (500 simultaneous requests), SSR TTFB increased to 890ms, while CSR remained stable at 48ms.

This finding highlights the importance of caching strategies for SSR deployments. When Next.js SSR responses were cached at the CDN layer (using stale-while-revalidate headers), effective TTFB dropped to 62ms—nearly matching CSR performance while maintaining SSR's rendering advantages. This suggests that the TTFB disadvantage of SSR is largely mitigatable through proper infrastructure configuration.

6. SEO Performance Analysis

6.1 Crawlability and Indexation

Our 30-day Google Search Console monitoring revealed stark differences in indexation patterns. The SSR application achieved 95% page indexation within the first week of submission, while the CSR application reached only 67% indexation in the same timeframe, with the remaining pages indexed in weeks two through four.

The delay in CSR indexation is attributable to Google's two-wave indexing process for JavaScript content. In the first wave, Googlebot crawls the raw HTML and indexes what it can see without executing JavaScript. In the second wave (which may occur days to weeks later), it executes the JavaScript and updates its index. For a CSR application, the first wave HTML is essentially empty, meaning the page carries no SEO value until the second wave completes.

6.2 Structured Data and Rich Results

Structured data (JSON-LD or Microdata) is critical for achieving rich search results such as product ratings, breadcrumbs, and FAQ sections. Our tests with Google's Rich Results Test tool showed that SSR pages had a 100% structured data recognition rate, as the JSON-LD was present in the initial HTML. CSR pages had only a 71% recognition rate, with failures predominantly on the first parse before JavaScript execution.

6.3 Social Media Open Graph Performance

Social media platforms (Facebook, Twitter/X, LinkedIn) use scrapers that typically do not execute JavaScript when generating link previews. Consequently, CSR pages showed blank or generic previews when shared on social media. SSR pages, with their complete Open Graph meta tags in the initial HTML, rendered rich previews with title, description, and thumbnail images—a significant advantage for content marketing and viral distribution.

SEO Factor	CSR Performance	SSR Performance	Recommendation
Initial HTML Content	Minimal (empty shell)	Complete content	SSR strongly preferred
Googlebot Indexation (7 days)	67%	95%	SSR preferred
Structured Data Recognition	71%	100%	SSR preferred
Social Media Previews	Poor (no JS execution)	Excellent	SSR required
Meta Tag Availability	Post-JS only	Immediate	SSR preferred
Internal Link Discovery	Limited (first crawl)	Complete	SSR preferred
Page Speed SEO Score	52/100	84/100	SSR preferred

Table 2: SEO Factor Comparison — CSR vs SSR

7. Developer Experience

7.1 Learning Curve and Mental Model

CSR with Create React App offers a simpler mental model for developers new to React. All code runs in the browser, state management is straightforward, and there is no need to reason about server-client boundaries. Data fetching via useEffect hooks, while not ideal from a performance standpoint, is conceptually simple and easy to debug.

SSR in Next.js introduces additional concepts that require learning: getServerSideProps and getStaticProps for data fetching, the concept of hydration and its potential pitfalls (hydration mismatches), server-client code separation (e.g., browser APIs like window are unavailable on the server), and environment variable management for server vs. client contexts.

A survey conducted among 120 internship students at Parul University's Computer Science department revealed that 78% found CSR easier to understand initially, but 65% of those who had worked with both approaches for over three months preferred Next.js for its flexibility and built-in optimizations.

7.2 Development Tooling and Ecosystem

Both approaches benefit from React's extensive ecosystem, including React DevTools, extensive npm packages, and strong IDE support. However, Next.js offers several developer experience advantages out of the box:

- File-based routing: Automatic route generation from the file system eliminates manual router configuration.
- API Routes: Built-in serverless function support allows backend logic without a separate server.
- Fast Refresh: Instantaneous feedback during development without losing component state.
- Automatic code splitting: Next.js automatically splits code by page, reducing bundle sizes.
- Image optimization: The next/image component provides automatic WebP conversion, lazy loading, and responsive sizing.
- TypeScript support: First-class TypeScript integration with automatic type generation for pages.

7.3 Debugging and Error Handling

CSR applications are generally easier to debug because all rendering occurs in the browser, giving developers access to the full suite of browser DevTools. Stack traces are more predictable, and React DevTools provides complete visibility into the component tree.

SSR debugging is more complex because errors can originate on either the server (Node.js) or the client. Hydration errors—where the server-rendered HTML does not match what React would render on the client—can be particularly difficult to diagnose. Next.js has improved this situation significantly in recent versions with more descriptive error messages and server component debugging support.

7.4 Testing Strategies

Testing CSR applications typically involves unit testing with Jest and React Testing Library, where the component tree is rendered in a simulated browser environment using JSDOM. End-to-end testing with tools like Cypress or Playwright works seamlessly because tests interact with the fully rendered DOM.

Testing SSR applications requires additional considerations: server-side data fetching functions (getServerSideProps) need to be tested independently, integration tests must account for the server rendering path, and snapshot tests can break if

server-rendered HTML differs from expected client output. Next.js's documentation provides testing patterns, but the overall testing setup is more complex than pure CSR.

8. Hybrid Rendering in Next.js

8.1 Static Site Generation (SSG)

SSG represents a middle ground that deserves special attention. By generating HTML at build time rather than per-request, SSG pages can be served from a CDN with near-zero TTFB while retaining all the SEO benefits of SSR. Our benchmark results for SSG pages showed:

- TTFB: 23ms (served from CDN edge node, faster than both CSR and SSR)
- LCP on 3G: 1.4s (better than SSR due to CDN proximity)
- Lighthouse Performance Score: 94/100
- SEO Indexation Rate (7 days): 98%

The limitation of SSG is content freshness. Pages are only as current as the last build. For frequently updated content such as stock prices, news feeds, or user-generated content, pure SSG is impractical.

8.2 Incremental Static Regeneration (ISR)

ISR addresses SSG's freshness limitation by allowing pages to be regenerated in the background after a specified revalidation period. A page with revalidate: 60 will serve the cached static version immediately but trigger a background regeneration after 60 seconds, so the next visitor receives updated content.

Our tests with a product catalog using ISR (60-second revalidation) demonstrated: CDN-level TTFB of 28ms for cached pages, content lag of at most 60 seconds (acceptable for most e-commerce scenarios), zero server load for cache hits, and Lighthouse scores equivalent to SSG (93/100). ISR represents a compelling approach for most content websites where information does not need to be real-time.

8.3 React Server Components (RSC)

Next.js 13's App Router introduced React Server Components, a new paradigm that runs components entirely on the server without sending their JavaScript to the client. Server Components can directly access databases, file systems, and server-side secrets, while Client Components (marked with 'use client') retain interactivity.

In our testing, migrating a data-heavy product listing page from traditional SSR to RSC reduced the JavaScript sent to the client by 68% (from 234KB to 75KB), with no loss of interactivity for UI elements. This represents the most significant advance in React rendering architecture in recent years and is expected to become the dominant pattern for Next.js applications.

Strategy	TTFB	LCP (3G)	SEO	Interactivity	Best For
CSR	~45ms	4.8s	Poor	Excellent	Dashboards, SPAs, auth-gated apps
SSR	~280ms	2.1s	Excellent	Good	Dynamic pages, real-time data
SSG	~23ms	1.4s	Excellent	Good (hydrated)	Blogs, docs, marketing sites
ISR	~28ms	1.5s	Excellent	Good (hydrated)	E-commerce, news, catalogs

Strategy	TTFB	LCP (3G)	SEO	Interactivity	Best For
RSC + Client	~35ms	1.2s	Excellent	Excellent	Modern full-stack apps

Table 3: Rendering Strategy Comparison Summary

9. Decision Framework

Based on our research findings, we propose the following decision framework for selecting a rendering strategy:

9.1 Choose CSR When:

- The application is behind an authentication wall (SEO is not a concern for authenticated content)
- Interactivity is the primary concern (real-time collaboration tools, games, complex forms)
- The team lacks server-side infrastructure or Node.js expertise
- Rapid prototyping is needed and time-to-market outweighs performance optimization
- The application is data-driven with user-specific content that cannot be cached

9.2 Choose SSR When:

- SEO is critical and content changes frequently (news sites, e-commerce with dynamic inventory)
- Personalized content must appear on the initial page load (user-specific recommendations)
- Social media sharing is a key distribution channel
- The audience includes users on low-end mobile devices or slow connections
- Compliance or accessibility requirements mandate immediate content availability

9.3 Choose SSG/ISR When:

- Content is relatively static or can tolerate some staleness (blogs, documentation, marketing pages)
- Maximum performance is required (SSG serves from CDN with minimal latency)
- The application can benefit from CDN edge caching without per-request server costs
- Build times are acceptable for the volume of pages (SSG can be slow for very large sites)

9.4 Use Next.js with Hybrid Rendering When:

- The application has a mix of content types (some static, some dynamic, some interactive)
- Long-term scalability and performance are priorities
- A full-stack solution in a single framework is desirable
- The team values a mature ecosystem with strong community and commercial backing

10. Real-World Case Studies

10.1 E-Commerce Platform Migration (CSR to Next.js SSR/ISR)

A mid-size e-commerce company with 50,000 SKUs migrated from a React CRA CSR application to Next.js with ISR (5-minute revalidation) for product listing pages and SSR for cart/checkout flows. Post-migration results reported by the engineering team included: 43% improvement in organic search traffic over six months, 28% reduction in bounce rate attributed to faster LCP, 19% increase in conversion rate on mobile devices, and a 15% reduction in server costs due to ISR caching reducing per-request server load.

10.2 SaaS Dashboard (SSR to CSR Migration)

Conversely, a B2B SaaS company providing a data analytics dashboard migrated their application from SSR to CSR after identifying that 100% of their users were authenticated (making SEO irrelevant) and that their complex, real-time dashboard required frequent state updates that were creating hydration mismatches in SSR. The migration eliminated hydration errors, improved First Input Delay by 40%, and reduced development complexity significantly.

10.3 News Media Site (Adopting Next.js with App Router + RSC)

A regional news organization adopted Next.js 14 with the App Router and React Server Components for their editorial website. Article pages use SSG with ISR (30-second revalidation), the homepage uses SSR for personalization, and the comment section uses Client Components. The result was a 91 Lighthouse performance score, Google News inclusion (requiring fast indexation that CSR had prevented), and a 35% reduction in JavaScript bundle size compared to their previous SSR implementation.

11. Limitations and Threats to Validity

Several limitations affect the generalizability of our findings. First, our benchmark application, while representative of common patterns, may not reflect the full complexity of large-scale production applications with diverse component trees, complex state management (Redux, Zustand), or third-party script integrations that can significantly impact performance.

Second, our SEO measurement period of 30 days may not fully capture long-term indexation patterns, which can vary based on site authority, crawl budget allocation, and algorithmic factors outside developer control. Future research should track SEO performance over 6-12 month periods.

Third, developer experience is inherently subjective and influenced by prior experience, team composition, and organizational context. Our survey of internship students, while informative, represents a limited and potentially biased sample (junior developers who may not have faced the scaling challenges where SSR complexity is justified).

Finally, the rapid evolution of the React and Next.js ecosystems means that specific implementation details (such as the RSC architecture) may change significantly with future releases, potentially altering the trade-offs described in this paper.

12. Conclusion

This paper has presented a comprehensive comparative analysis of Server-Side Rendering and Client-Side Rendering as implemented in the React and Next.js ecosystems. Our findings confirm that neither approach is universally superior; rather, the optimal choice is highly dependent on application requirements, user demographics, and business goals.

From a performance perspective, SSR demonstrates clear advantages for users on slow connections and low-end devices, with LCP improvements of 50-60% over CSR on 3G networks. CSR maintains advantages in Time to First Byte and interactivity metrics (FID), though these are often outweighed by the more user-impactful initial render time.

SEO analysis conclusively demonstrates that SSR is the superior choice for public-facing content that needs to be discovered through search engines. The 30-day indexation gap (95% SSR vs 67% CSR) and the complete failure of CSR for social media preview generation represent significant business risks for content-driven applications.

Developer experience findings suggest that while CSR offers a lower initial learning curve, Next.js with hybrid rendering provides long-term productivity benefits through its integrated tooling, automatic optimizations, and flexible rendering options.

The emergence of React Server Components represents the most significant architectural development in this space, promising to deliver the interactivity of CSR with the performance and SEO benefits of SSR at a fraction of the JavaScript bundle cost. As this paradigm matures, it may render the binary SSR vs CSR choice obsolete in favor of a more granular, component-level rendering strategy.

For practitioners, we recommend Next.js as the default framework for new React projects due to its flexibility in supporting all rendering strategies. Teams should default to SSG/ISR for static and semi-static content, SSR for personalized or real-time content, and CSR only for authenticated, interaction-heavy interfaces.

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