Astle.js: A Reactive JavaScript SDK for Commerce Applications

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Abstract

We present Astle.js, a reactive JavaScript SDK designed for building commerce applications with predictable state management and real-time synchronization. Astle.js introduces a unidirectional data flow architecture where application state is derived from an immutable event log, enabling time-travel debugging, optimistic updates, and seamless offline support. The SDK provides declarative bindings for React, Angular, and vanilla JavaScript, abstracting the complexity of real-time commerce operations—cart management, inventory tracking, and checkout flows—behind a consistent API. We evaluate Astle.js through integration with production e-commerce storefronts, demonstrating reduced development time, improved user experience through optimistic rendering, and simplified debugging of complex state transitions.

1 Introduction

Modern e-commerce user interfaces present significant state management challenges. A shopping cart alone involves multiple interacting concerns: local quantity adjustments, server synchronization, inventory validation, price calculations, and promotional rules. Traditional imperative approaches—mutating shared state in response to events—produce code that is difficult to reason about, test, and debug.

The emergence of reactive programming paradigms, particularly Facebook's Flux architecture [1] and its derivatives, offers a path forward. However, generic state management libraries require substantial boilerplate to handle commerce-specific concerns: API integration, optimistic updates, conflict resolution, and real-time synchronization.

Astle.js bridges this gap by providing a commerce-specific reactive SDK. Our contributions are:

1. A domain-specific state model capturing commerce primitives (cart, checkout, customer) with well-defined state transitions.
2. An event-sourced architecture enabling time-travel debugging and deterministic state reconstruction.
3. Optimistic update semantics with automatic rollback on server rejection.
4. Real-time synchronization via WebSocket with offline queuing and reconnection handling.

2 Background

2.1 State Management Evolution

JavaScript application state management has progressed through several paradigms:

jQuery era (2006–2012). State scattered across DOM elements and global variables. Event handlers mutate state imperatively. Testing requires DOM simulation.

MVC/MVVM era (2010–2014). Backbone.js, Angular 1.x, and Knockout introduce structured patterns. Two-way data binding simplifies UI synchronization but complicates debugging—changes propagate bidirectionally, making causality difficult to trace.

Unidirectional flow era (2014–present). Flux, Redux, and similar architectures enforce unidirectional data flow: actions describe intent, reducers compute new state, views render state. This pattern enables predictable state transitions and time-travel debugging.

2.2 Reactive Programming

Reactive programming treats data as streams that propagate changes automatically. Key concepts include:

- **Observables**: Values that change over time and notify subscribers.
- **Operators**: Transformations on streams (map, filter, combine).
- **Subscriptions**: Connections between observables and side effects.

Libraries such as RxJS [3] provide comprehensive reactive primitives. Astle.js builds upon these foundations while providing commerce-specific abstractions.

2.3 E-Commerce State Complexity

Commerce applications present unique state challenges:

- **Distributed truth**: Cart state exists on client and server; synchronization is required.
- **Temporal coupling**: Inventory availability changes during user sessions.
- **External dependencies**: Payment processors, shipping calculators, and tax services introduce latency and failure modes.
- **Promotional logic**: Discounts depend on cart contents, customer segment, and time.

3 Architecture

3.1 Core Principles

Astle.js adheres to three architectural principles:

Principle 1: State as Derived Value. Application state is computed from an ordered sequence of events. The current state is a pure function of the event history:

$$\text{state}_n = \text{reduce}(\text{state}_0, [\text{event}_1, \ldots, \text{event}_n]) \quad (1)$$

Principle 2: Events are Immutable. Once recorded, events cannot be modified. Corrections are represented as compensating events, preserving audit history.

Principle 3: Optimistic by Default. User actions produce immediate local state changes. Server confirmation or rejection triggers reconciliation.

3.2 Event Model

Events in Astle.js follow a standard schema:

Listing 1: Event schema

```
interface Event {
  id: string;            // UUID
  type: string;          // e.g., "
     cart/addItem"
  payload: object;       // Event-
     specific data
  timestamp: number;     // Unix
     milliseconds
  origin: "local" | "remote";
  status: "pending" | "confirmed" |
     "rejected";
}
```

Events transition through states:

1. `pending`: Applied locally, awaiting server confirmation.
2. `confirmed`: Server acknowledged; event is permanent.
3. `rejected`: Server rejected; compensating event generated.

3.3 State Domains

Astle.js partitions state into domains with independent reducers:

3.3.1 Cart Domain

The cart domain manages shopping cart state:

Listing 2: Cart state shape

```
interface CartState {
  items: CartItem[];
  subtotal: number;
  discounts: Discount[];
  total: number;
  itemCount: number;
}
```

Cart events include:

- `cart/addItem`: Add product to cart.
- `cart/updateQuantity`: Change item quantity.
- `cart/removeItem`: Remove item from cart.
- `cart/applyCoupon`: Apply promotional code.
- `cart/clear`: Empty cart contents.

3.3.2 Checkout Domain

The checkout domain manages the checkout flow:

Listing 3: Checkout state machine

```
type CheckoutStatus =
  | "idle"
  | "collecting_info"
  | "processing_payment"
  | "confirming"
  | "complete"
  | "failed";
```

State transitions are guarded by validation:

$$\text{transition}(s, e) = \begin{cases} s' & \text{if valid}(s, e) \\ s & \text{otherwise} \end{cases} \tag{2}$$

3.3.3 Customer Domain

The customer domain tracks authentication and profile state:

Listing 4: Customer state

```
interface CustomerState {
  authenticated: boolean;
  profile: Profile | null;
  addresses: Address[];
  paymentMethods: PaymentMethod[];
}
```

3.4 Reducer Composition

Domain reducers compose into the root reducer:

Listing 5: Root reducer composition

```
const rootReducer = combineReducers
    ({
  cart: cartReducer,
  checkout: checkoutReducer,
  customer: customerReducer,
  ui: uiReducer,
});

function cartReducer(state =
    initialCart, event) {
  switch (event.type) {
    case "cart/addItem":
      return addItemToCart(state,
          event.payload);
    case "cart/updateQuantity":
      return updateCartQuantity(
          state, event.payload);
    // ...
    default:
      return state;
  }
}
```

3.5 Optimistic Updates

Astle.js implements optimistic updates through a three-phase protocol:

Phase 1: Local Application. User action generates event with `status: "pending"`. Reducer applies event to produce optimistic state. UI renders immediately.

Phase 2: Server Submission. Event dispatched to server via WebSocket or HTTP. Client awaits confirmation.

Phase 3: Reconciliation. Server responds with confirmation or rejection.

- **Confirmed**: Event status updates; state unchanged.
- **Rejected**: Compensating event generated; state rolls back.

Listing 6: Optimistic middleware

```
function optimisticMiddleware(store)
    {
  return next => async event => {
    // Phase 1: Apply locally
    event.status = "pending";
    next(event);

    try {
      // Phase 2: Submit to server
      const response = await api.
          submit(event);

      // Phase 3a: Confirm
      next({ type: "event/confirm",
          payload: { id: event.id }
          });
    } catch (error) {
      // Phase 3b: Reject and
          compensate
      next({ type: "event/reject",
          payload: { id: event.id,
          error } });
      next(compensate(event));
    }
  };
}
```

3.6 Real-Time Synchronization

Astle.js maintains a persistent WebSocket connection for real-time updates:

Listing 7: WebSocket synchronization

```
class SyncClient {
  constructor(store, url) {
    this.store = store;
    this.socket = new WebSocket(url)
        ;
    this.queue = [];

    this.socket.onmessage = (msg) =>
        {
      const event = JSON.parse(msg.
          data);
      event.origin = "remote";
      this.store.dispatch(event);
    };

    this.socket.onclose = () => {
      this.reconnect();
    };
  }

  send(event) {
    if (this.socket.readyState ===
        WebSocket.OPEN) {
      this.socket.send(JSON.
          stringify(event));
    } else {
      this.queue.push(event);
    }
  }
}
```

Server-originated events (inventory updates, price changes) flow through the same reducer pipeline, ensuring consistent state regardless of event origin.

4 API Design

4.1 Store Initialization

Listing 8: Store creation

```
import { createStore } from "astle";

const store = createStore({
  apiKey: "pk_live_xxx",
  endpoint: "https://api.hanzo.ai",
  initialState: {
    cart: loadFromStorage("cart"),
  },
});
```

4.2 Actions

Actions are factory functions returning events:

Listing 9: Action creators

```
import { actions } from "astle";

// Add item to cart
```

```
store.dispatch(actions.cart.addItem
    ({
  productId: "prod_123",
  variantId: "var_456",
  quantity: 2,
}));

// Apply coupon
store.dispatch(actions.cart.
    applyCoupon({
  code: "SAVE20",
}));

// Begin checkout
store.dispatch(actions.checkout.
    begin());
```

4.3 Selectors

Selectors derive values from state:

Listing 10: Selectors

```
import { selectors } from "astle";

const cart = selectors.cart.getCart(
    store.getState());
const itemCount = selectors.cart.
    getItemCount(store.getState());
const isCheckoutReady = selectors.
    checkout.isReady(store.getState()
    );
```

Selectors are memoized for performance:

Listing 11: Memoized selector

```
const getCartTotal = createSelector(
  [getItems, getDiscounts],
  (items, discounts) => {
    const subtotal = items.reduce((
        sum, item) => sum + item.
        price * item.quantity, 0);
    const discountAmount = discounts
        .reduce((sum, d) => sum + d.
        amount, 0);
    return subtotal - discountAmount
        ;
  }
);
```

4.4 React Bindings

Astle.js provides React hooks for seamless integration:

Listing 12: React integration

```
import { useCart, useCheckout } from
    "astle/react";

function CartPage() {
  const { items, total, addItem,
      removeItem } = useCart();
  const { begin, status } =
      useCheckout();

  return (
    <div>
      {items.map(item => (
        <CartItem key={item.id} item
            ={item} onRemove={() =>
            removeItem(item.id)} />
      ))}
      <Total amount={total} />
      <button onClick={begin}
          disabled={status !== "idle
          "}>
        Checkout
      </button>
    </div>
  );
}
```

5 Implementation Details

5.1 Event Persistence

Events persist to IndexedDB for offline support and session recovery:

Listing 13: IndexedDB persistence

```
class EventStore {
  async append(event) {
    const db = await this.getDB();
    const tx = db.transaction("
        events", "readwrite");
    await tx.objectStore("events").
        add(event);
  }

  async replay(fromTimestamp) {
    const db = await this.getDB();
    const events = await db.getAll("
        events");
    return events
      .filter(e => e.timestamp >=
          fromTimestamp)
      .sort((a, b) => a.timestamp -
         b.timestamp);
  }
}
```

5.2 Conflict Resolution

When offline edits conflict with server state, Astle.js applies last-writer-wins with vector clocks for ordering:

$$\text{resolve}(e_1, e_2) = \begin{cases} e_1 & \text{if } \text{vc}(e_1) > \text{vc}(e_2) \\ e_2 & \text{otherwise} \end{cases} \quad (3)$$

For inventory conflicts, server state always wins:

Listing 14: Inventory conflict resolution

```
function resolveInventoryConflict(
   local, remote) {
  // Server inventory is
     authoritative
  if (remote.available < local.
     quantity) {
    return {
      type: "cart/adjustQuantity",
      payload: {
        itemId: local.itemId,
        quantity: remote.available,
        reason: "inventory_adjusted
           ",
      },
    };
  }
  return null;
}
```

5.3 Performance Optimizations

Structural Sharing. Immutable updates share unchanged subtrees:

Listing 15: Structural sharing

```
function addItem(state, item) {
  return {
    ...state,
    items: [...state.items, item],
    // subtotal, total recomputed
  };
}
```

Batched Updates. Multiple synchronous dispatches batch into single render:

Listing 16: Update batching

```
store.batch(() => {
  store.dispatch(actions.cart.clear
     ());
  store.dispatch(actions.checkout.
     reset());
  store.dispatch(actions.ui.
     showConfirmation());
});
// Single render after all three
```

Lazy Computation. Expensive derivations compute on access:

Listing 17: Lazy selectors

```
const getShippingOptions =
   createLazySelector(
  [getCart, getAddress],
  async (cart, address) => {
    return await shippingApi.
       getOptions(cart, address);
  }
);
```

6 Evaluation

6.1 Developer Productivity

We measured development time for implementing common commerce features with Astle.js versus vanilla Redux:

Table 1: Development time comparison (hours)

Feature	Redux	Astle.js
Cart management	16	4
Checkout flow	24	8
Real-time inventory	12	2
Offline support	20	4
Total	72	18

Astle.js reduces implementation time by 75% through domain-specific abstractions.

6.2 Bundle Size

Astle.js bundle (11.4 KB) is smaller than equivalent Redux setup (22 KB) while providing more

Table 2: Bundle size comparison (KB, gzipped)

Library	Size
Astle.js core	8.2
Astle.js + React	11.4
Redux + middleware	6.8
Custom commerce logic	15.2

functionality.

6.3 Runtime Performance

We benchmarked state update performance:

Table 3: Operations per second (higher is better)

Operation	Redux	Astle.js
Simple dispatch	125,000	98,000
Cart add item	45,000	52,000
Full checkout	8,200	9,100

Astle.js performs comparably to Redux, with commerce-specific operations slightly faster due to optimized reducers.

6.4 Case Study: Production Deployment

We deployed Astle.js to a fashion retailer's storefront (50,000 daily active users). Key metrics:

- Cart abandonment reduced 12% (optimistic updates reduced perceived latency).
- Mobile conversion increased 8% (offline support enabled subway shopping).
- Support tickets reduced 23% (time-travel debugging simplified issue reproduction).

7 Related Work

Redux [2] established unidirectional data flow for JavaScript applications. Astle.js extends this pattern with commerce-specific reducers and optimistic update semantics.

MobX [4] offers transparent reactive state with automatic dependency tracking. While MobX simplifies local state management, it lacks built-in support for event sourcing and server synchronization.

Apollo Client [5] provides GraphQL-centric state management with caching and optimistic updates. Astle.js achieves similar goals for REST APIs with a smaller footprint.

8 Conclusion

Astle.js demonstrates that domain-specific state management significantly reduces development complexity for commerce applications. By encoding commerce primitives—carts, checkout flows, customer profiles—directly into the SDK, we eliminate boilerplate while preserving the benefits of reactive, unidirectional architectures.

The event-sourced foundation enables powerful capabilities: time-travel debugging, offline support, and deterministic state reconstruction. These capabilities translate directly to improved developer experience and user satisfaction.

Future work will extend Astle.js with machine learning-driven prefetching (predicting likely cart additions) and integration with emerging state management patterns (React Server Components, Suspense).

References

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[6] M. Fowler, "CQRS," *martinfowler.com*, 2010.

[7] M. Fowler, “Event Sourcing,” *martin-fowler.com*, 2005.