Image Carousel Component with Animations and Touch Support

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Clarify the Problem and Requirements

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Problem Understanding

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Design a flexible and performant image carousel component that provides smooth animations, touch/swipe support, and excellent user experience across all devices and input methods. The component should be reusable, accessible, and capable of handling various content types while maintaining consistent performance with large image sets.

Functional Requirements

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- **Navigation Controls**: Previous/next buttons, dot indicators, thumbnail navigation

- **Touch Gestures**: Swipe navigation, pinch-to-zoom, long press interactions
- **Keyboard Support**: Arrow keys, Enter/Space, Tab navigation, focus management
- **Autoplay Features**: Auto-advance with pause on hover/focus, configurable timing
- **Image Support**: Multiple formats (JPEG, PNG, WebP, GIF), lazy loading, responsive images
- **Customization**: Transition effects, animation timing, layout options, theming
- **Content Flexibility**: Images, videos, mixed content, custom slide components
- **Responsive Design**: Adaptive layout for different screen sizes and orientations

Non-Functional Requirements

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- **Performance**: <16ms frame time, 60fps animations, <200ms image load time
- **Accessibility**: WCAG 2.1 AA compliance, screen reader support, keyboard navigation
- **Cross-platform**: Consistent experience across desktop, tablet, mobile devices
- **Browser Support**: Modern browsers with graceful degradation for older versions
- **Memory Efficiency**: Optimal memory usage for large image sets, proper cleanup
- **Bundle Size**: Lightweight component, tree-shakeable, minimal dependencies
- **Touch Responsiveness**: <100ms touch response time, smooth gesture tracking

Key Assumptions

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- Typical carousel size: 5-50 images, maximum 200 images
- Image sizes: 100KB-2MB per image, various aspect ratios
- Usage patterns: Browse-focused with occasional deep exploration
- Device capabilities: Modern smartphones to high-end desktops
- Network conditions: 3G to high-speed connections
- User interactions: Mix of touch, mouse, and keyboard navigation
- Content types: Primarily images with occasional video or rich media

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High-Level Design (HLD)

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System Architecture Overview

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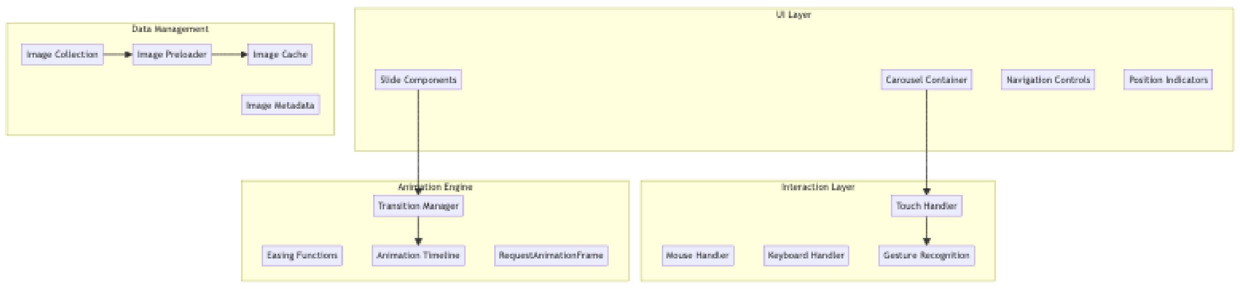

Carousel Data Model

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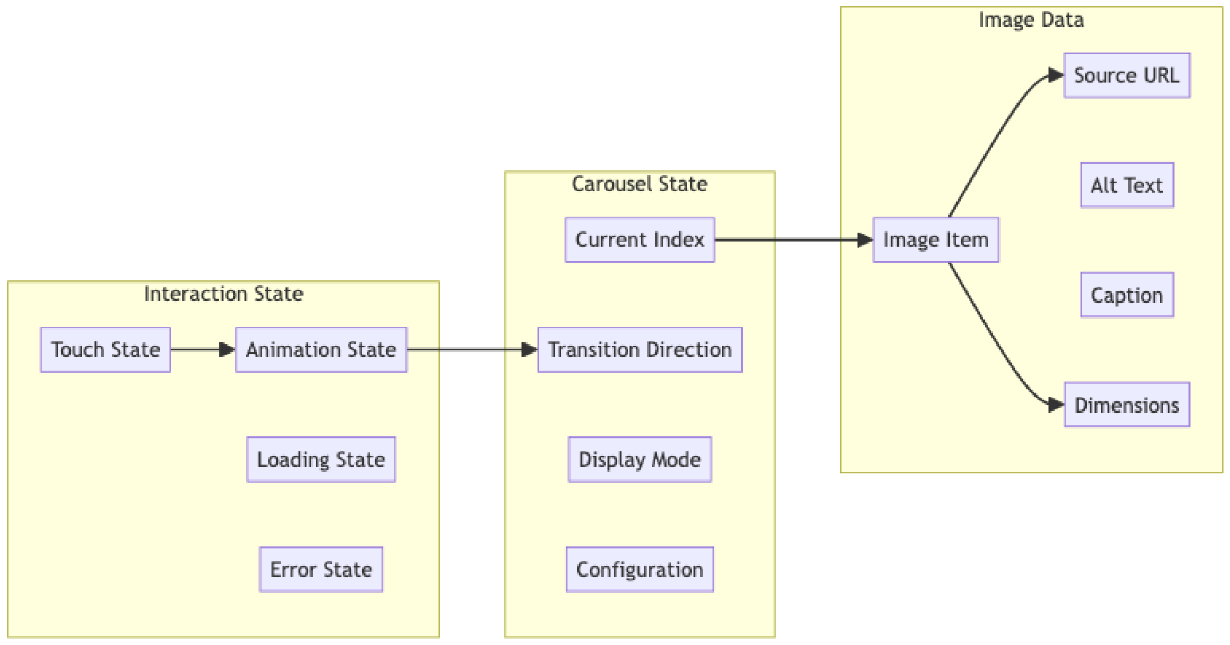

Low-Level Design (LLD)

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Touch Gesture Recognition

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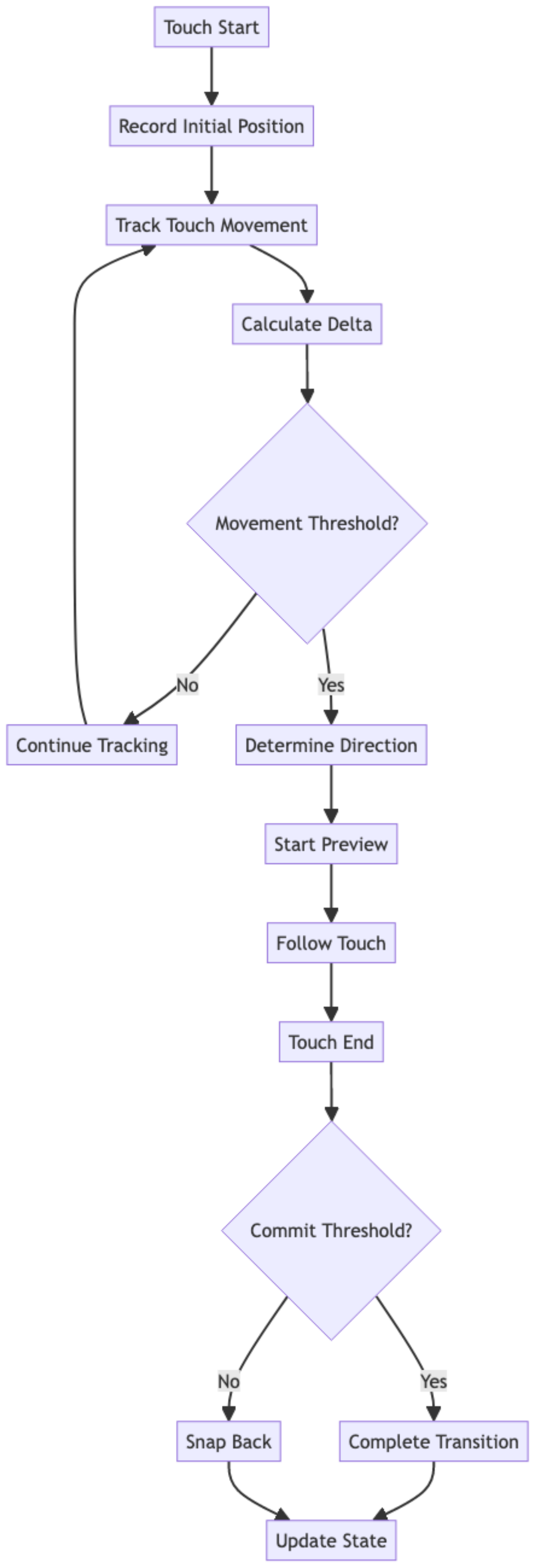
Touch Start
Record Initial Position
Track Touch Movement
Calculate Delta
Movement Threshold?
No
Yes
Continue Tracking
Determine Direction
Start Preview
Follow Touch
Touch End
Commit Threshold?
No
Yes
Snap Back
Complete Transition
Update State

Animation State Machine

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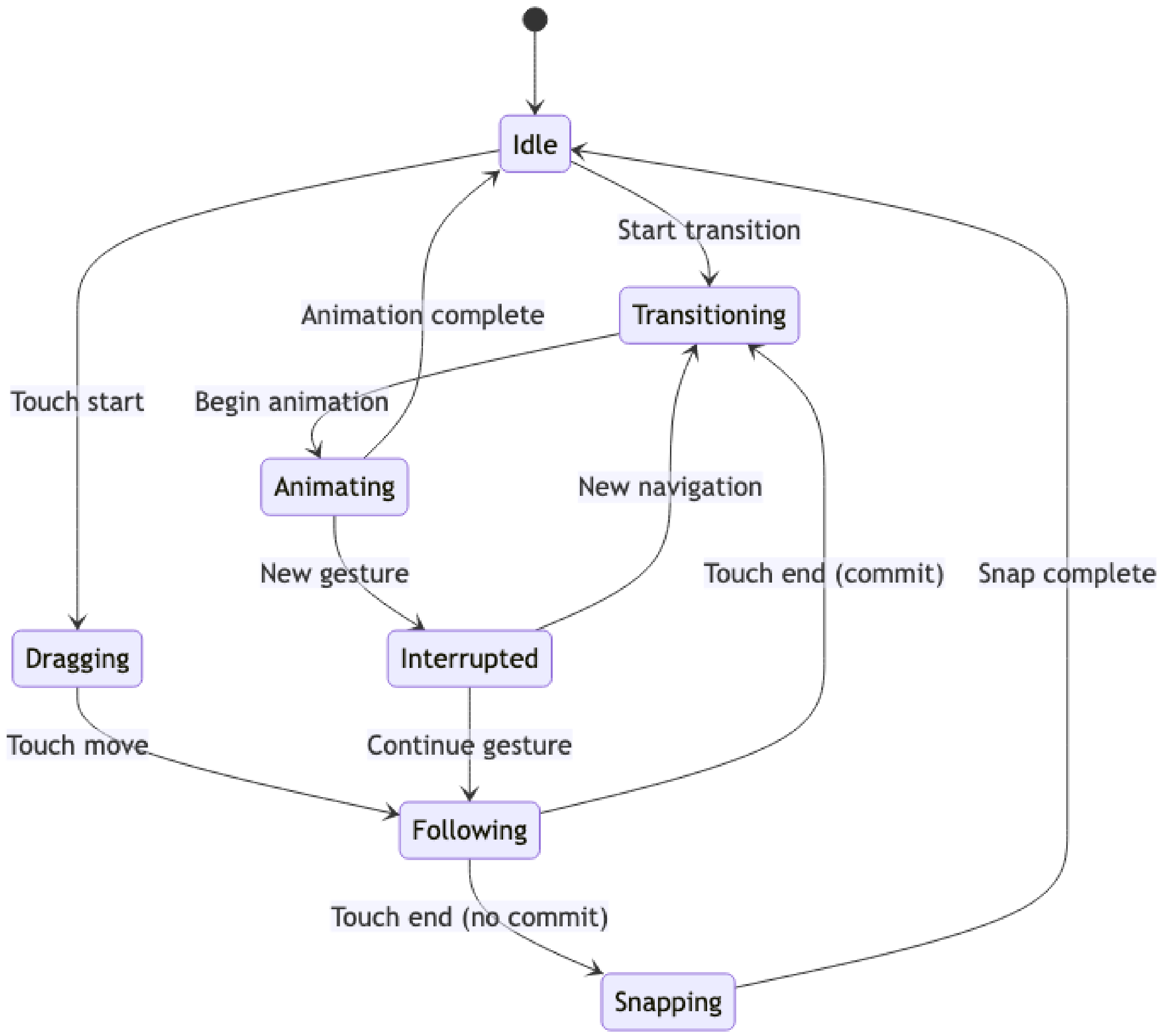

Image Loading Pipeline

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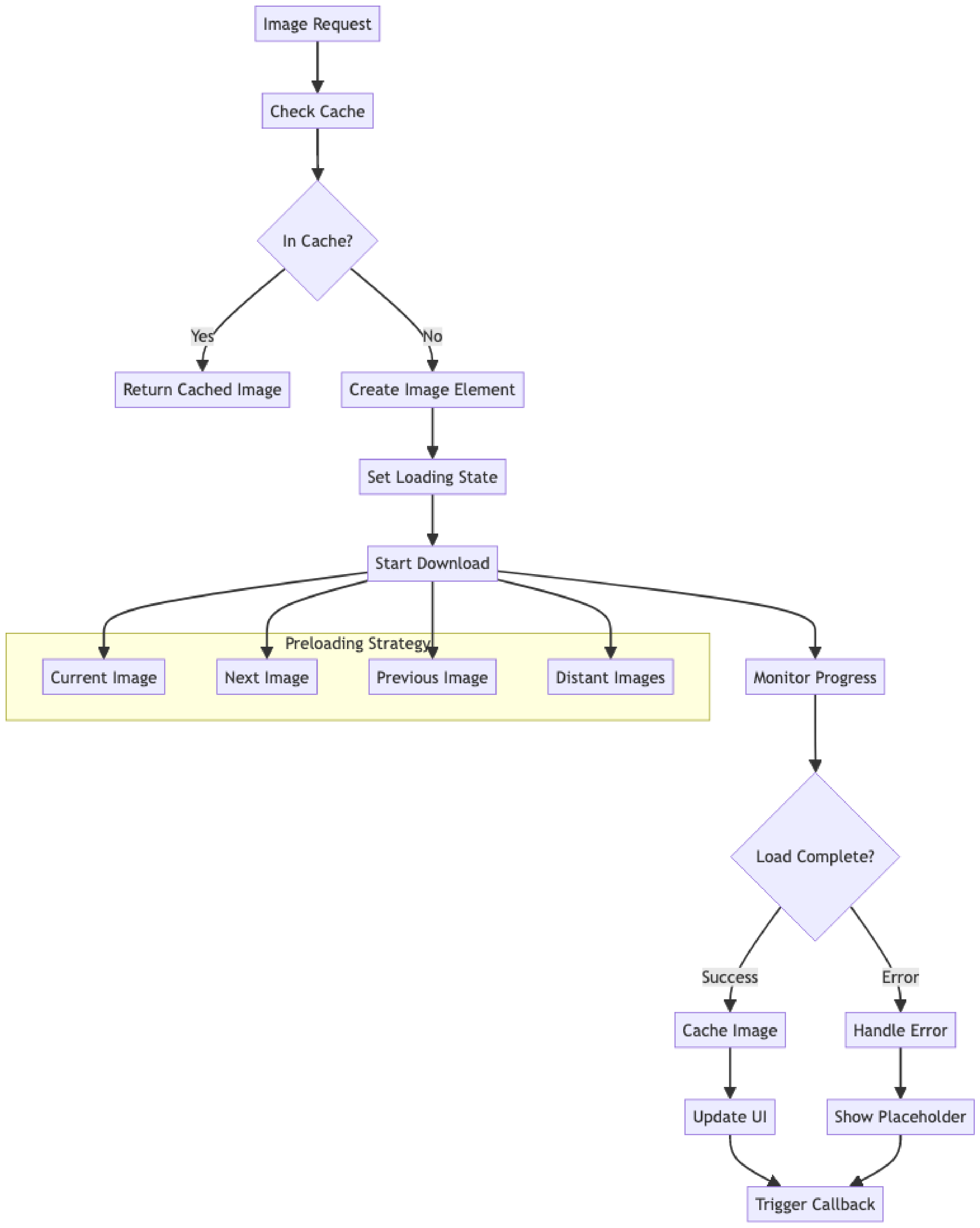

Core Algorithms

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1. Touch Gesture Recognition Algorithm

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Purpose: Accurately detect and respond to touch gestures for carousel navigation.

Touch State Structure:

```
TouchState = {
  startX: number,
  startY: number,
  currentX: number,
  currentY: number,
  deltaX: number,
  deltaY: number,
  velocity: number,
  timestamp: number,
  isTracking: boolean
}
```

Gesture Detection Algorithm:

```
function processTouchMove(touch):
  currentTime = Date.now()
  deltaTime = currentTime - touch.timestamp

  touch.deltaX = touch.currentX - touch.startX
  touch.deltaY = touch.currentY - touch.startY

  // Calculate velocity
  if deltaTime > 0:
    touch.velocity = touch.deltaX / deltaTime

  // Determine if horizontal swipe
  isHorizontalSwipe = Math.abs(touch.deltaX) > Math.abs(touch.deltaY)

  // Check movement threshold
  hasMinMovement = Math.abs(touch.deltaX) > SWIPE_THRESHOLD

  if isHorizontalSwipe and hasMinMovement:
    startTransition(touch.deltaX > 0 ? 'prev' : 'next', touch.deltaX)
```

Velocity-based Momentum: - Calculate touch velocity for momentum scrolling - Apply easing based on velocity magnitude - Implement inertial scrolling for natural feel - Consider device capabilities for performance optimization

2. Smooth Animation Algorithm

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Easing Functions:

```
EasingType = 'linear' | 'ease-in' | 'ease-out' | 'ease-in-out' | 'cubic-bezier'

function calculateEasing(progress, type):
  switch type:
    case 'ease-out':
      return 1 - Math.pow(1 - progress, 3)
    case 'ease-in':
      return Math.pow(progress, 3)
    case 'ease-in-out':
      return progress < 0.5
        ? 4 * Math.pow(progress, 3)
        : 1 - Math.pow(-2 * progress + 2, 3) / 2
```

Animation Timeline Management:

```
function animateTransition(fromIndex, toIndex, duration):
  startTime = performance.now()
  startPosition = getCurrentPosition()
  endPosition = calculateTargetPosition(toIndex)
  distance = endPosition - startPosition

  function animate(currentTime):
    elapsed = currentTime - startTime
    progress = Math.min(elapsed / duration, 1)

    easedProgress = calculateEasing(progress, 'ease-out')
    currentPosition = startPosition + (distance * easedProgress)

    updateCarouselPosition(currentPosition)

    if progress < 1:
      requestAnimationFrame(animate)
    else:
      onAnimationComplete()

  requestAnimationFrame(animate)
```

Frame Rate Optimization: - Use RequestAnimationFrame for smooth 60fps animations - Implement frame skipping for performance on slower devices - Batch DOM updates to minimize reflow/repaint - Use CSS transforms for hardware acceleration

3. Image Preloading Strategy

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Intelligent Preloading Algorithm:

```
function preloadImages(currentIndex, images):
  priorities = [
    { index: currentIndex, priority: 1 },
    { index: currentIndex + 1, priority: 2 },
    { index: currentIndex - 1, priority: 2 },
    { index: currentIndex + 2, priority: 3 },
    { index: currentIndex - 2, priority: 3 }
  ]

  for priority in priorities:
    if isValidIndex(priority.index):
      scheduleImageLoad(images[priority.index], priority.priority)
```

Adaptive Loading Strategy:

```
function adaptiveImageLoading(image, viewport):
  // Calculate optimal image size based on viewport
  optimalWidth = viewport.width * devicePixelRatio
  optimalHeight = viewport.height * devicePixelRatio

  // Select appropriate image source
  if image.srcSet:
    selectedSrc = selectFromSrcSet(image.srcSet, optimalWidth)
  else:
    selectedSrc = image.src

  // Apply lazy loading based on network conditions
  if isSlowConnection():
    return loadImageProgressive(selectedSrc)
  else:
    return loadImageDirect(selectedSrc)
```

Memory Management: - Implement LRU cache for loaded images - Unload distant images to conserve memory - Use WeakMap for automatic garbage collection - Monitor memory usage and adjust cache size

4. Responsive Layout Algorithm

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Viewport Adaptation:

```
function calculateLayout(containerWidth, images):
  layouts = []

  for image in images:
    aspectRatio = image.width / image.height

    // Calculate dimensions to fit container
    if aspectRatio > 1:
      // Landscape image
      width = containerWidth
      height = containerWidth / aspectRatio
    else:
      // Portrait image
      height = containerWidth / aspectRatio
      width = containerWidth

    layouts.push({
      width: width,
      height: height,
      objectFit: calculateObjectFit(image, { width, height })
    })

  return layouts
```

Breakpoint Management:

```
Breakpoints = {
  mobile: { max: 768, columns: 1, gap: 10 },
  tablet: { min: 769, max: 1024, columns: 2, gap: 15 },
  desktop: { min: 1025, columns: 3, gap: 20 }
}

function getLayoutConfig(screenWidth):
  for breakpoint in Breakpoints:
    if matchesBreakpoint(screenWidth, breakpoint):
      return breakpoint

  return Breakpoints.desktop // default
```

5. Accessibility Navigation Algorithm

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Keyboard Navigation:

```
function handleKeyboardNavigation(event):
  switch event.key:
    case 'ArrowLeft':
      navigateTo(currentIndex - 1)
      announceSlideChange('previous')
    case 'ArrowRight':
      navigateTo(currentIndex + 1)
      announceSlideChange('next')
    case 'Home':
      navigateTo(0)
      announceSlideChange('first')
    case 'End':
      navigateTo(images.length - 1)
      announceSlideChange('last')
    case 'Enter':
    case 'Space':
      triggerSlideAction(currentIndex)
```

Screen Reader Announcements:

```
function announceSlideChange(direction):
  message = `Slide ${currentIndex + 1} of ${images.length}`

  if images[currentIndex].alt:
    message += `, ${images[currentIndex].alt}`

  if images[currentIndex].caption:
    message += `, ${images[currentIndex].caption}`

  ariaLiveRegion.textContent = message
```

Component Architecture

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Carousel Component Hierarchy

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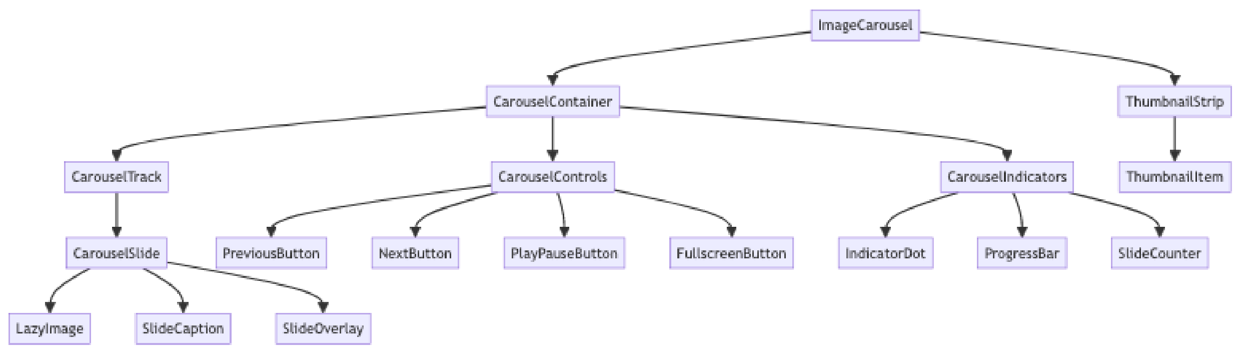

State Management Architecture

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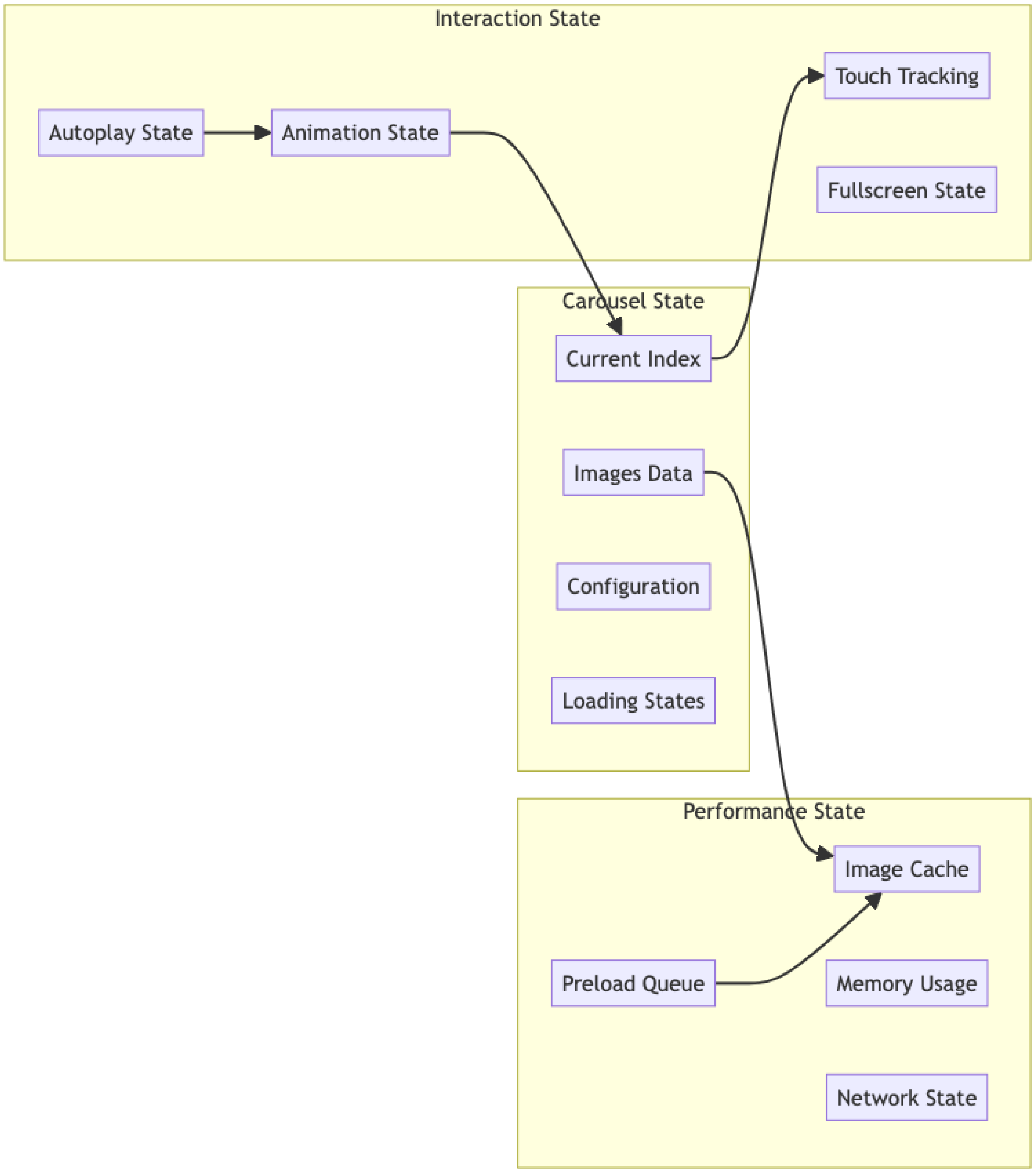

React Component Implementation 􀀀 Back to Top

ImageCarousel.jsx

```
import React, { useState, useEffect, useCallback, useRef } from 'react';
import { CarouselProvider } from './CarouselContext';
import CarouselContainer from './CarouselContainer';
import { useImagePreloader } from './hooks/useImagePreloader';
import { useSwipeGestures } from './hooks/useSwipeGestures';

const ImageCarousel = ({
  images = [],
  initialIndex = 0,
  autoplay = false,
  autoplayInterval = 3000,
  showThumbnails = true,
  showIndicators = true,
  showControls = true,
  loop = true,
  swipeEnabled = true,
  lazy = true,
  aspectRatio = '16:9'
}) => {
  const [currentIndex, setCurrentIndex] = useState(initialIndex);
  const [isPlaying, setIsPlaying] = useState(autoplay);
  const [isFullscreen, setIsFullscreen] = useState(false);
  const [direction, setDirection] = useState('next');
  const [isTransitioning, setIsTransitioning] = useState(false);
  const [loadedImages, setLoadedImages] = useState(new Set());

  const carouselRef = useRef(null);
  const autoplayTimerRef = useRef(null);
  const touchStartRef = useRef(null);

  const { preloadImages } = useImagePreloader();
  const { onTouchStart, onTouchMove, onTouchEnd } = useSwipeGestures({
    onSwipeLeft: () => goToNext(),
    onSwipeRight: () => goToPrevious(),
    enabled: swipeEnabled
  });

  // Preload images
  useEffect(() => {
    if (lazy) {
      preloadImages(images, currentIndex, 2); // Preload 2 images ahead/behind
    } else {
      preloadImages(images);
    }
  }, [images, currentIndex, lazy, preloadImages]);

  // Handle autoplay
```

```
useEffect(() => {
  if (isPlaying && images.length > 1) {
    autoplayTimerRef.current = setInterval(() => {
      goToNext();
    }, autoplayInterval);
  } else {
    clearInterval(autoplayTimerRef.current);
  }

  return () => clearInterval(autoplayTimerRef.current);
}, [isPlaying, autoplayInterval, images.length]);

// Pause autoplay on user interaction
useEffect(() => {
  const handleUserInteraction = () => {
    if (isPlaying) {
      setIsPlaying(false);
      setTimeout(() => setIsPlaying(autoplay), 5000); // Resume after 5s
    }
  };

  const carousel = carouselRef.current;
  if (carousel) {
    carousel.addEventListener('mouseenter', handleUserInteraction);
    carousel.addEventListener('focus', handleUserInteraction);

    return () => {
      carousel.removeEventListener('mouseenter', handleUserInteraction);
      carousel.removeEventListener('focus', handleUserInteraction);
    };
  }
}, [isPlaying, autoplay]);

const goToSlide = useCallback((index, slideDirection = 'next') => {
  if (isTransitioning) return;

  const newIndex = Math.max(0, Math.min(images.length - 1, index));

  if (newIndex !== currentIndex) {
    setDirection(slideDirection);
    setIsTransitioning(true);
    setCurrentIndex(newIndex);

    setTimeout(() => {
      setIsTransitioning(false);
      }, 300); // Match transition duration
    }
  }, [currentIndex, images.length, isTransitioning]);

  const goToNext = useCallback(() => {
    if (currentIndex < images.length - 1) {
      goToSlide(currentIndex + 1, 'next');
    } else if (loop) {
      goToSlide(0, 'next');
    }
  }, [currentIndex, images.length, loop, goToSlide]);

  const goToPrevious = useCallback(() => {
    if (currentIndex > 0) {
      goToSlide(currentIndex - 1, 'prev');
    } else if (loop) {
      goToSlide(images.length - 1, 'prev');
    }
  }, [currentIndex, images.length, loop, goToSlide]);

  const togglePlay = useCallback(() => {
    setIsPlaying(!isPlaying);
  }, [isPlaying]);

  const toggleFullscreen = useCallback(() => {
    if (!isFullscreen) {
      if (carouselRef.current?.requestFullscreen) {
        carouselRef.current.requestFullscreen();
      }
    } else {
      if (document.exitFullscreen) {
        document.exitFullscreen();
      }
    }
    setIsFullscreen(!isFullscreen);
  }, [isFullscreen]);

  const handleImageLoad = useCallback((index) => {
    setLoadedImages(prev => new Set(prev).add(index));
  }, []);

  const handleKeyDown = useCallback((e) => {
    switch (e.key) {
      case 'ArrowLeft':
        e.preventDefault();
      goToPrevious();
      break;
    case 'ArrowRight':
      e.preventDefault();
      goToNext();
      break;
    case ' ':
      e.preventDefault();
      togglePlay();
      break;
    case 'Escape':
      if (isFullscreen) {
        toggleFullscreen();
      }
      break;
  }
}, [goToPrevious, goToNext, togglePlay, isFullscreen, toggleFullscreen]);

useEffect(() => {
  document.addEventListener('keydown', handleKeyDown);
  return () => document.removeEventListener('keydown', handleKeyDown);
}, [handleKeyDown]);

const canGoNext = currentIndex < images.length - 1 || loop;
const canGoPrevious = currentIndex > 0 || loop;

const value = {
  images,
  currentIndex,
  direction,
  isPlaying,
  isFullscreen,
  isTransitioning,
  loadedImages,
  canGoNext,
  canGoPrevious,
  showThumbnails,
  showIndicators,
  showControls,
  aspectRatio,
  goToSlide,
  goToNext,
  goToPrevious,
  togglePlay,
  toggleFullscreen,
    onImageLoad: handleImageLoad
  };

  return (
    <CarouselProvider value={value}>
      <div
        ref={carouselRef}
        className={`image-carousel ${isFullscreen ? 'fullscreen' : ''}`}
        onTouchStart={onTouchStart}
        onTouchMove={onTouchMove}
        onTouchEnd={onTouchEnd}
        tabIndex={0}
      >
        <CarouselContainer />
      </div>
    </CarouselProvider>
  );
};

export default ImageCarousel;
```

CarouselContainer.jsx

```
import React, { useContext } from 'react';
import { CarouselContext } from './CarouselContext';
import CarouselTrack from './CarouselTrack';
import CarouselControls from './CarouselControls';
import CarouselIndicators from './CarouselIndicators';
import ThumbnailStrip from './ThumbnailStrip';

const CarouselContainer = () => {
  const {
    showControls,
    showIndicators,
    showThumbnails,
    aspectRatio
  } = useContext(CarouselContext);

  const aspectRatioStyle = {
    aspectRatio: aspectRatio.replace(':', '/')
  };

  return (
    <div className="carousel-container">
      <div className="carousel-main" style={aspectRatioStyle}>
        <CarouselTrack />
        {showControls && <CarouselControls />}
        {showIndicators && <CarouselIndicators />}
      </div>

      {showThumbnails && <ThumbnailStrip />}
    </div>
  );
};

export default CarouselContainer;
```

CarouselTrack.jsx

```
import React, { useContext, useRef, useEffect } from 'react';
import { CarouselContext } from './CarouselContext';
import CarouselSlide from './CarouselSlide';

const CarouselTrack = () => {
  const {
    images,
    currentIndex,
    direction,
    isTransitioning
  } = useContext(CarouselContext);

  const trackRef = useRef(null);

  useEffect(() => {
    if (trackRef.current) {
      const translateX = -currentIndex * 100;
      trackRef.current.style.transform = `translateX(${translateX}%)`;
    }
  }, [currentIndex]);

  return (
    <div className="carousel-track-container">
      <div
        ref={trackRef}
        className={`carousel-track ${isTransitioning ? 'transitioning' : ''} ${direction
      >
        {images.map((image, index) => (
          <CarouselSlide
            key={`${image.id || index}-${image.src}`}
            image={image}
            index={index}
            isActive={index === currentIndex}
            isVisible={Math.abs(index - currentIndex) <= 1}
          />
        ))}
      </div>
    </div>
  );
};

export default CarouselTrack;
```

CarouselSlide.jsx

```
import React, { useContext, useState } from 'react';
import { CarouselContext } from './CarouselContext';
import LazyImage from './LazyImage';

const CarouselSlide = ({ image, index, isActive, isVisible }) => {
  const { onImageLoad } = useContext(CarouselContext);
  const [isLoaded, setIsLoaded] = useState(false);

  const handleImageLoad = () => {
    setIsLoaded(true);
    onImageLoad(index);
  };

  return (
    <div
      className={`carousel-slide ${isActive ? 'active' : ''}`}
      role="tabpanel"
      aria-label={`Slide ${index + 1} of ${image.length}`}
    >
      {isVisible && (
        <>
          <LazyImage
            src={image.src}
            alt={image.alt || `Slide ${index + 1}`}
            onLoad={handleImageLoad}
            className="slide-image"
          />

          {!isLoaded && (
            <div className="slide-loading">
              <div className="loading-spinner" />
            </div>
          )}
          {image.caption && (
            <div className="slide-caption">
              <h3>{image.title}</h3>
              <p>{image.caption}</p>
            </div>
          )}

          {image.overlay && (
            <div className="slide-overlay">
              {image.overlay}
            </div>
          )}
        </>
      )}
    </div>
  );
};

export default CarouselSlide;
```

LazyImage.jsx

```
import React, { useState, useRef, useEffect } from 'react';

const LazyImage = ({ src, alt, onLoad, className, placeholder }) => {
  const [isLoaded, setIsLoaded] = useState(false);
  const [isInView, setIsInView] = useState(false);
  const [error, setError] = useState(false);
  const imgRef = useRef(null);

  useEffect(() => {
    const observer = new IntersectionObserver(
      ([entry]) => {
        if (entry.isIntersecting) {
          setIsInView(true);
          observer.disconnect();
        }
      },
      { threshold: 0.1 }
    );

    if (imgRef.current) {
      observer.observe(imgRef.current);
    }

    return () => observer.disconnect();
  }, []);

  const handleLoad = () => {
    setIsLoaded(true);
    onLoad?.();
  };

  const handleError = () => {
    setError(true);
  };

  return (
    <div ref={imgRef} className={`lazy-image-container ${className}`}>
      {isInView && (
        <>
          <img
            src={src}
            alt={alt}
            onLoad={handleLoad}
            onError={handleError}
            className={`lazy-image ${isLoaded ? 'loaded' : ''}`}
            style={{ display: error ? 'none' : 'block' }}
          />

          {error && (
            <div className="image-error">
              <span>Failed to load image</span>
            </div>
          )}

          {!isLoaded && !error && (
            <div className="image-placeholder">
              {placeholder || <div className="placeholder-shimmer" />}
            </div>
          )}
        </>
      )}
    </div>
  );
};

export default LazyImage;
```

Advanced Features

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Autoplay with Smart Pausing

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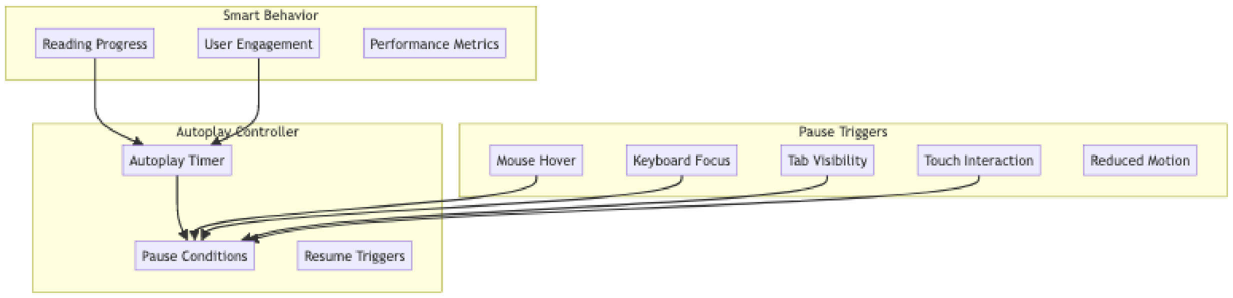

Gesture Customization

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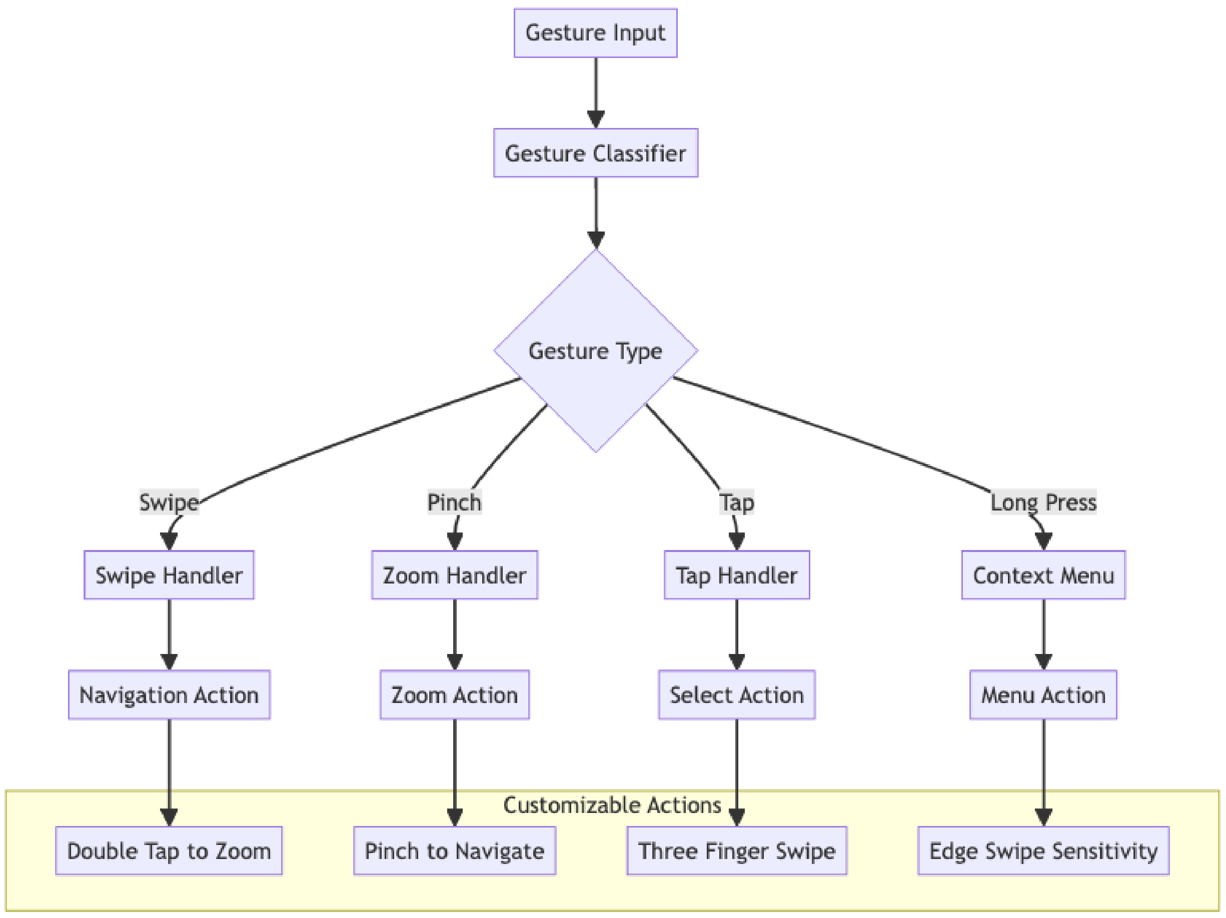

TypeScript Interfaces & Component Props

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Core Data Interfaces

```
interface CarouselImage {
  id: string;
  src: string;
  alt: string;
  width: number;
  height: number;
  caption?: string;
  thumbnailSrc?: string;
  srcSet?: string[];
  sizes?: string;
  blurDataURL?: string;
  metadata?: ImageMetadata;
```

```
}

interface CarouselState {
  currentIndex: number;
  images: CarouselImage[];
  isAutoPlaying: boolean;
  isLoading: boolean;
  direction: 'prev' | 'next';
  touchStartX: number;
  isDragging: boolean;
  dragOffset: number;
  zoomLevel: number;
  isZoomed: boolean;
}

interface CarouselSettings {
  autoPlay: boolean;
  autoPlayInterval: number;
  infinite: boolean;
  showThumbnails: boolean;
  showDots: boolean;
  showArrows: boolean;
  keyboard: boolean;
  swipe: boolean;
  zoom: boolean;
  fade: boolean;
  lazy: boolean;
}

interface TouchGesture {
  startX: number;
  startY: number;
  currentX: number;
  currentY: number;
  deltaX: number;
  deltaY: number;
  velocity: number;
  direction: 'left' | 'right' | 'up' | 'down';
  distance: number;
}

interface ZoomState {
  scale: number;
  translateX: number;
  translateY: number;
  minScale: number;
  maxScale: number;
  centerX: number;
  centerY: number;
}
```

Component Props Interfaces

```
interface ImageCarouselProps {
  images: CarouselImage[];
  initialIndex?: number;
  onImageChange?: (index: number, image: CarouselImage) => void;
  onImageLoad?: (image: CarouselImage) => void;
  onImageError?: (image: CarouselImage, error: Error) => void;
  settings?: Partial<CarouselSettings>;
  className?: string;
  style?: React.CSSProperties;
  width?: number | string;
  height?: number | string;
}

interface CarouselControlsProps {
  currentIndex: number;
  totalImages: number;
  onPrevious: () => void;
  onNext: () => void;
  onGoTo: (index: number) => void;
  showArrows?: boolean;
  showDots?: boolean;
  showCounter?: boolean;
  disabled?: boolean;
}

interface ThumbnailStripProps {
  images: CarouselImage[];
  currentIndex: number;
  onThumbnailClick: (index: number) => void;
  thumbnailSize?: 'sm' | 'md' | 'lg';
  orientation?: 'horizontal' | 'vertical';
  maxVisible?: number;
  showScrollbar?: boolean;
}

interface ZoomControlsProps {
  zoomLevel: number;
  minZoom: number;
  maxZoom: number;
  onZoomIn: () => void;
  onZoomOut: () => void;
  onResetZoom: () => void;
  onFitToContainer: () => void;
  showControls?: boolean;
  position?: 'top-left' | 'top-right' | 'bottom-left' | 'bottom-right';
}
```

API Reference

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Image Management

- `loadImage(src: string)` - Preload image with caching and error handling
- `preloadImages(indices: number[])` - Preload multiple images for smooth navigation
- `optimizeImage(image, size)` - Get optimized image URL for current viewport
- `generateThumbnail(image, size)` - Generate thumbnail with specified dimensions
- `validateImageSrc(src)` - Validate image URL and check accessibility

Carousel Navigation

- `goToSlide(index: number)` - Navigate to specific slide with animation
- `nextSlide()` - Move to next slide with wrap-around support
- `previousSlide()` - Move to previous slide with wrap-around support
- `startAutoPlay()` - Begin automatic slide progression
- `stopAutoPlay()` - Stop automatic slide progression and preserve state

Touch & Gesture Controls

- `enableSwipeGestures()` - Activate touch/mouse swipe navigation
- `disableSwipeGestures()` - Disable gesture controls temporarily
- `configureTouchSensitivity(threshold)` - Set swipe distance threshold
- `enableKeyboardNavigation()` - Activate arrow key and space bar controls
- `handlePinchZoom(event)` - Process pinch-to-zoom gesture events

Zoom & Transform

- `zoomIn(factor?: number)` - Increase zoom level with optional factor
- `zoomOut(factor?: number)` - Decrease zoom level with bounds checking
- `resetZoom()` - Reset zoom to original scale and center position

- `fitToContainer()` - Scale image to fit container dimensions
- `panImage(deltaX, deltaY)` - Pan zoomed image within viewport bounds

Performance & Loading

- `setLazyLoading(enabled: boolean)` - Configure lazy loading behavior
- `prefetchImages(strategy)` - Prefetch images with specified strategy
- `measurePerformance()` - Get timing metrics for carousel operations
- `optimizeForDevice()` - Apply device-specific performance settings
- `clearImageCache()` - Clear cached images to free memory

Events & Callbacks

- `addEventListener(event, callback)` - Subscribe to carousel events
- `removeEventListener(event, callback)` - Unsubscribe from events
- `onSlideChange(callback)` - Register slide change event handler
- `onImageLoad(callback)` - Register image load completion handler
- `onZoomChange(callback)` - Register zoom level change handler

Configuration

- `updateSettings(settings)` - Update carousel configuration dynamically
- `getSettings()` - Get current carousel configuration
- `resetToDefaults()` - Reset all settings to default values
- `exportConfiguration()` - Export current settings as JSON
- `importConfiguration(config)` - Import and apply configuration

Performance Optimizations

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Memory Management

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Image Cache Strategy:

```
ImageCache = {
  active: Map<string, HTMLImageElement>,
  preloaded: WeakMap<string, HTMLImageElement>,
  maxMemory: number,
  currentUsage: number
}
```

Optimization Techniques: - Implement intelligent image unloading - Use intersection observer for lazy loading - Compress images based on device capabilities - Implement progressive image enhancement - Monitor memory usage and adjust cache size

Animation Performance

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Hardware Acceleration: - Use CSS transforms instead of changing layout properties - Leverage GPU acceleration for smooth animations - Implement will-change CSS property strategically - Use translate3d for force hardware acceleration - Minimize paint and layout operations

Frame Rate Optimization:

```
PerformanceMonitor = {
  frameTime: number[],
  averageFrameTime: number,
  droppedFrames: number,
  adaptiveQuality: boolean
}
```

Adaptive Quality Settings: - Reduce animation complexity on slower devices - Disable effects when frame rate drops - Use lower quality images for smooth transitions - Implement progressive enhancement based on capabilities

Network Optimization

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Smart Preloading: - Consider network speed for preload strategy - Use service workers for advanced caching - Implement image format negotiation (WebP, AVIF) - Use compression and lazy loading - Prioritize critical path images

Security Considerations

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Content Security

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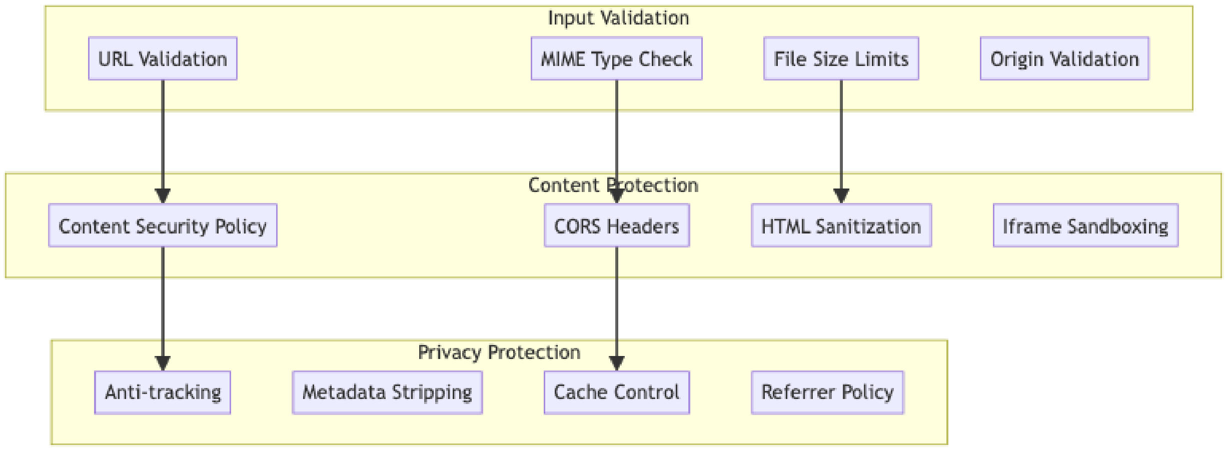

Data Protection

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Image Source Validation: - Validate image URLs against whitelist - Implement proper CORS policies - Sanitize image metadata - Use secure image proxy when necessary - Implement rate limiting for image requests

Accessibility Implementation

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Screen Reader Support

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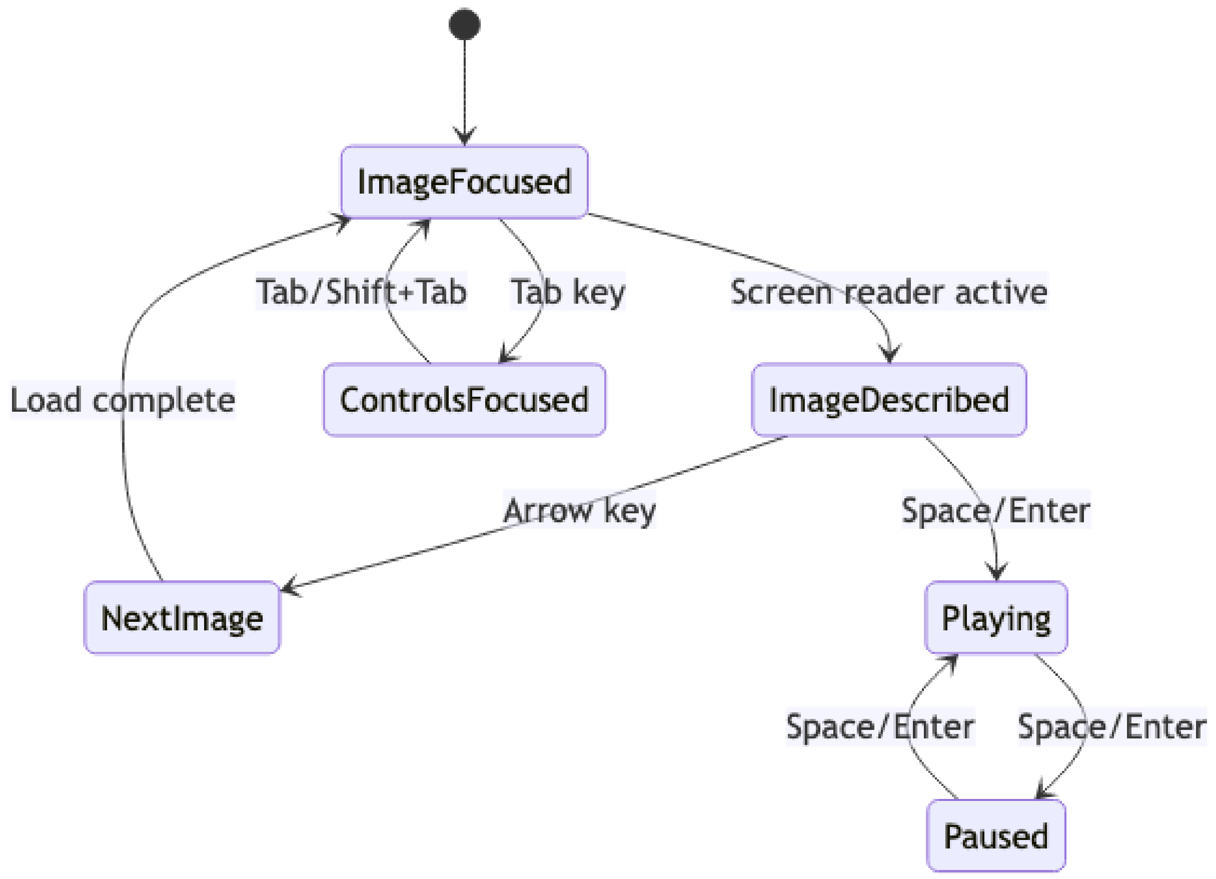

Accessibility Features: - Comprehensive ARIA labels and roles - Keyboard navigation support - High contrast mode compatibility - Reduced motion support - Screen reader announcements - Focus management during transitions

Keyboard Navigation

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Navigation Patterns: - Arrow keys for slide navigation - Tab key for control focus - Enter/Space for activation - Home/End for first/last slide - Escape for fullscreen exit

Testing Strategy

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Unit Testing Focus Areas

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Core Algorithm Testing: - Touch gesture recognition accuracy - Animation timing and easing - Image preloading logic - Layout calculation correctness

Component Testing: - Carousel navigation behavior - Touch interaction handling - Keyboard accessibility - Responsive layout adaptation

Integration Testing

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Cross-browser Testing: - Touch device compatibility - Animation performance across browsers - Image loading behavior - Accessibility compliance

Performance Testing: - Memory usage patterns - Animation frame rates - Image loading times - Large dataset handling

End-to-End Testing

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User Experience Testing: - Complete navigation flows - Touch gesture interactions - Accessibility workflows - Performance on various devices

Trade-offs and Considerations

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Performance vs Features

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- **Smooth animations**: GPU usage vs battery life
- **Image quality**: File size vs visual fidelity
- **Preloading**: Memory usage vs loading speed
- **Touch responsiveness**: CPU usage vs interaction quality

Accessibility vs UX

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- **Autoplay**: User experience vs accessibility guidelines
- **Gestures**: Touch convenience vs keyboard accessibility
- **Animations**: Visual appeal vs motion sensitivity
- **Navigation**: Intuitive controls vs comprehensive accessibility

Scalability Considerations

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- **Image count**: Performance vs feature richness
- **File sizes**: Loading speed vs image quality
- **Device support**: Feature coverage vs performance
- **Network conditions**: Functionality vs loading speed

This image carousel system provides a comprehensive foundation for modern image display with advanced features like smooth touch interactions, intelligent preloading, and robust accessibility while maintaining high performance across all devices and network conditions.