Optimized SAR Preprocessing Pipeline

1. Fundamental Corrections

This stage focuses on essential, non-negotiable corrections that form the foundation of any SAR analysis.

- **Apply Orbit File:** Corrects satellite position errors for accurate geolocation, which is crucial for tasks like dimension estimation and data fusion.
- **Radiometric Calibration:** Converts raw pixel values to physically meaningful backscatter coefficients (e.g., $\sigma 0$, $\gamma 0$). This ensures consistent quantitative interpretation and comparability across different acquisitions and sensors.

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2. Geometric & Terrain Correction

This stage rectifies geometric distortions and normalizes backscatter variations caused by terrain.

- **Range-Doppler Terrain Correction:** Maps slant-range image pixels to their true ground positions using a Digital Elevation Model (DEM), correcting geometric distortions and ensuring accurate spatial measurements.
- **Radiometric Terrain Flattening (RTF):** Normalizes backscatter variations caused by terrain slopes, which provides consistent radiometric values for better interpretation and classification.

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3. Noise & Clutter Suppression (Adaptive)

This stage uses a selective, adaptive approach to handle noise and clutter, minimizing over-processing.

- **Adaptive Speckle Filtering:** Instead of applying multiple filters sequentially, use a single, powerful adaptive filter like a **Lee Sigma Filter**. For deep learning workflows, a trained model like **ID-CNN** or a **SAR-DDRM** can be used as a superior alternative to traditional filters.
- **Sea-Land Segmentation:** For maritime tasks, remove land clutter using a dedicated segmentation model or thresholding to avoid false positives from coastal areas.
- **Multi-Level Sparse Optimization or Transformer-Based Clutter Removal (Optional):** Use these advanced techniques only when dealing with high sea

states or difficult clutter scenarios, as they are computationally intensive. This step can be skipped for calmer waters.

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4. Target Enhancement & Isolation

This stage focuses on improving the quality of detected vessels and preparing them for subsequent analysis.

- **Super-Resolution (Optional):** Apply a technique like **TaylorGAN** or **Diffusion Models** only when dealing with low-resolution data or very small targets where fine details are essential.
- **Target Segmentation & Cropping:** After initial detection, segment the vessel from the background. This can involve **shadow detection** to help estimate vessel dimensions and orientation. Then, **auto-crop** a tight bounding box around the isolated vessel to reduce background noise and expedite processing.
- **Wake-Ship Separation:** If direction prediction is a priority, separate the vessel wake from the ship body to ensure the ship's features are not distorted by the wake.

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5. Advanced Feature Extraction & Analysis

This stage is modular and depends on the specific end goal (e.g., direction prediction vs. classification).

- **Wake Detection & Directional Clue Extraction:** To infer a vessel's heading from its wake, use the **Radon Transform with Z-Score Normalization** to detect wake patterns.
- **Doppler Shift Estimation:** For scenarios without visible wakes or for more precise heading, analyze **Doppler shifts or motion-induced distortions** using techniques like **SAR-GMTI**.
- **Hand-Crafted Features:** For classification tasks, extract features like **Hu Moments**, **Histogram of Oriented Gradients (HOG)**, or **Local Radar Cross-Section (LRCS)** to supplement deep learning features or use in a traditional classifier.
- **Data Augmentation (for Machine Learning):** Use techniques like **geometric transformations** (rotation, flip) and **noise injection** to improve a model's robustness and generalization, especially with smaller datasets.

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6. Data Fusion & Packaging

This final stage prepares the data for model consumption and provides a well-structured output.

- **Data Normalization:** Use **Z-Score Normalization** or **Histogram Matching** to standardize intensity distributions across different scenes, which improves model consistency.
- **AIS Matching (Optional):** If AIS data is available, fuse it with the SAR detections to provide ground truth for training and validation, including ship identity, type, velocity, and heading.
- **Export Cropped Chips & Metadata JSON:** Output each processed vessel as a separate image chip (e.g., GeoTIFF or PNG) with a corresponding metadata file. This metadata should include coordinates, dimensions, heading, and classification labels.
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