OSTEO-CORE: FRACTURE TRIAGE SYSTEM

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Security Classification: INTERNAL / RESTRICTED

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ABSTRACT

OSTEO-CORE is a high-performance, minimalist diagnostic support system designed for the rapid triage and localization of bone fractures in digital X-ray radiography. Leveraging a modified **Residual Network (ResNet-18)** architecture, the system performs binary classification (Fracture vs. Normal) and generates weakly-supervised localization maps via **Gradient-weighted Class Activation Mapping (Grad-CAM)**.

The system is engineered with a **"Dark Glass"** aesthetic, prioritizing visual clarity for radiological environments. It features a robust data ingestion pipeline capable of handling terabyte-scale tabular datasets via memory-mapping and is deployed as a single, multi-threaded Windows executable (.exe) for zero-dependency clinical integration.

1.0 INTRODUCTION & STRATEGIC OVERVIEW

1.1 Project Objectives

The primary objective of OSTEO-CORE is to reduce diagnostic latency in emergency trauma settings. Fracture triage is a critical bottleneck; a missed fracture can lead to malunion, chronic pain, and disability. OSTEO-CORE acts as a "second reader," flagging high-probability cases for immediate human review.

Key Performance Indicators (KPIs):

- **AUROC:** > 0.85 (Target)
- **Inference Latency:** < 200ms per image
- **False Negative Rate:** < 5% at 95% Sensitivity

1.2 Design Philosophy: "Dark Glass"

Radiology reading rooms are typically kept at low ambient light levels to maximize contrast perception. OSTEO-CORE adopts a "Dark Glass" aesthetic:

- **Background:** Void Black (#000000) to minimize glare.

- **Elements:** Semi-transparent, blurred surfaces (Glassmorphism).
- **Accents:** High-frequency Neon Cyan (#00f2ff) for critical indicators.

2.0 THEORETICAL FOUNDATIONS

2.1 Physics of Digital Radiography

An X-ray image is a projection shadowgram. The attenuation of the beam follows the Beer-Lambert Law:

$$I = I_0 e^{-\int \mu(z) dz}$$

Where μ is the linear attenuation coefficient. Bone, having a high atomic number (Calcium), absorbs more photons, resulting in a lower signal on the detector. A fracture represents a density discontinuity—a region of lower density (soft tissue/air) within the high-density bone cortex.

2.2 The Residual Learning Framework

Deep networks suffer from the vanishing gradient problem. OSTEO-CORE utilizes Residual Learning. Instead of learning a direct mapping $H(x)$, we learn a residual function $F(x) = H(x) - x$.

$$y = F(x, \{W_i\}) + x$$

The identity shortcut connection allows gradients to backpropagate unimpeded to earlier layers, enabling the training of deeper, more expressive networks necessary for capturing subtle bone trabeculae.

3.0 SYSTEM ARCHITECTURE

3.1 Unified Deployment Topology

The system has been refactored from a multi-process development environment into a **Unified Single-Process Topology**.

- **Launcher Engine:** A multi-threaded entry point (app_launcher.py) that initializes the FastAPI backend and Streamlit frontend concurrently.
- **Internal Resource Mapping:** Implements a resource_path() utility to handle absolute path mapping for model weights and assets within the PyInstaller _MEIPASS temporary directory.

3.2 Directory Taxonomy

```
OSTEO-CORE/
├── app_launcher.py      # Unified process manager & entry point
├── OSTEO-CORE.exe       # Final distributable binary (Single-File)
├── logo.ico / logo.png  # Branding & UI assets
```

```
├── src/               # CORE LOGIC
│   ├── models/        # fracture_model.pth (Trained Weights)
│   ├── backend/       # FastAPI inference server logic
│   ├── ui/            # streamlit_app.py (2026 Layout Standards)
│   ├── config.py      # Hyperparameters & THEME definitions
│   ├── model_arch.py  # ResNet-18 (Modified) Architecture
│   └── explainability.py# Grad-CAM implementation
└── installer.iss      # Inno Setup compilation script
```

4.0 DATA ENGINEERING & MODELING

4.1 Ingestion & Preprocessing

- **Memory Mapping:** The system uses np.load(mmap_mode='r') to create virtual arrays mapped to disk. This allows training and inference on datasets larger than physical RAM by paging in specific rows only when requested.
- **Normalization:** $X_{norm} = X / 255.0$ followed by Reshape to $(128, 128)$.
- **Quality Gate:** Before inference, images pass through a Laplacian blur detection filter. If the variance (σ^2) is below the threshold, the image is rejected to prevent false negatives.

4.2 Architecture: ResNet-18 (Modified)

- **Input Conv:** Conv2d(1, 64, kernel=7, stride=2, padding=3) (Adjusted for single-channel grayscale).
- **Classifier:** Linear layer (512, 1) outputting raw logits for binary classification.
- **Loss:** BCEWithLogitsLoss for numerical stability during training.

5.0 EXPLAINABILITY ENGINE (Grad-CAM)

To build clinical trust, the system visualizes the model's focus by computing gradients of the predicted class score y^c with respect to the feature maps A^k of the final convolutional layer.

$$\alpha_k^c = \frac{1}{Z} \sum_i \sum_j \frac{\partial y^c}{\partial A_{ij}^k}$$

The resulting heatmap is superimposed on the original X-ray:

- **Red (Hot):** Areas associated with high fracture probability.
- **Blue (Cold):** Normal bone or background.

6.0 FRONTEND & INSTALLATION

6.1 Streamlit 2026 Interface

The UI has been updated to comply with the **Streamlit 2026 standard**:

- **Responsive Scaling:** Replaced deprecated use_container_width with width="stretch" for adaptive image rendering across diverse clinical monitors.
- **Session State:** Persists the model in memory (st.session_state) to eliminate reload latency.

6.2 Deployment Pipeline

1. **PyInstaller:** Bundles the environment, dependencies (Torch, OpenCV, Streamlit), and the src folder into a single binary.
2. **Inno Setup:** Wraps the binary into an enterprise-grade installer (OSTEO-CORE_Setup.exe) with professional branding, desktop shortcuts, and LZMA2 compression.

7.0 ETHICS & SAFETY

WARNING: OSTEO-CORE is an investigational research tool. It is NOT FDA 510(k) cleared or CE marked.

- **Clinical Limitations:** The model may miss hairline fractures and can be affected by metal implants.
- **Bias Mitigation:** The documentation acknowledges demographic bias; pediatric growth plates may cause false positives if not validated against age-specific datasets.

END OF COMPENDIUM *Authorized by: Aadvit More*