Enhancing Diagnostic Reliability and Safety in Diabetic Retinopathy (DR) Screening on the Clinical Edge: A Scalable Deep Ensemble Meta-Learning Framework With Enhanced Uncertainty Estimation (Year 2)

Lin, Jophy (School: Manalapan High School)

Diabetic retinopathy (DR), a leading cause of vision loss projected to affect 130 million people by 2030, is often undetected until advanced stages due to subtle early symptoms, leading to costly treatments and irreversible damage. Existing AI models offer only best guesses without providing confidence metrics, a critical shortfall in high-stakes diagnostic applications. Additionally, current uncertainty quantification methods are impractical, non-scalable, and resource-intensive. Building on Year 1—where ensemble uncertainty estimation using diverse architectures achieved 93.70% unfiltered and up to 99.44% uncertainty-filtered accuracy—this project advances diagnostic precision by developing a scalable, efficient detection framework. In year 2, an ensemble comprising a single efficient architecture, particularly EfficientNetB2 after comparison, was trained on varied data subsets to induce diversity was created. By replacing majority voting with a neural meta-learner to aggregate logits, classification accuracy increased to 96.39%. Further, employing Monte Carlo dropout for uncertainty estimation achieved 99.51% maximum uncertainty-filtered accuracy, outperforming the accuracy-weighted entropy method of Year 1. Compared to Year 1, this enhanced approach cuts dropped samples from 69.2% to 5.62%, reducing uncertainty by 92% and increasing confidence by 3.1×, lowers model complexity to 45.55M parameters (1.5× fewer) and 3.47 GMACs (2.7× less), and decreases the false negative rate by 75.93% (from 15% to 3.61%). This novel framework reduces complexity and computational overhead, enabling deployment in edge computing and mobile environments, while simultaneously making DR detection safer and more reliable, and can easily be extended to other high-risk medical applications.

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