

Towards Open World Recognition

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Abstract

*With the advent of rich classification models and high computational power visual recognition systems have found many operational applications. Recognition in the real world poses multiple challenges that are not apparent in controlled lab environments. The datasets are dynamic and novel categories must be continuously detected and then added. At prediction time, a trained system has to deal with myriad unseen categories. Operational systems require minimal downtime, even to learn. To handle these operational issues, we present the problem of **Open World Recognition** and formally define it. We prove that thresholding sums of monotonically decreasing functions of distances in linearly transformed feature space can balance “open space risk” and empirical risk. Our theory extends existing algorithms for open world recognition. We present a protocol for evaluation of open world recognition systems. We present the **Nearest Non-Outlier (NNO)** algorithm that evolves model efficiently, adding object categories incrementally while detecting outliers and managing open space risk. We perform experiments on the ImageNet dataset with 1.2M+ images to validate the effectiveness of our method on large scale visual recognition tasks. NNO consistently yields superior results on open world recognition.*

1 Introduction

Over the past decade, datasets for building and evaluating visual recognition systems have increased both in size and variation. The size of datasets has increased from a few hundred images to millions of images, and the number of categories within the datasets has increased from tens of categories to more than a thousand categories. Co-evolution of rich classification models along with advances in datasets have resulted in many commercial applications [8, 40, 29]. A multitude of operational challenges are posed while porting recognition systems from controlled lab environments to the real world. A recognition system in the “open world” has to continuously update with additional object categories and be robust to unseen categories and have minimum downtime.

Despite the obvious dynamic and open nature of the world, a vast majority of recognition systems assume a *static* and closed world model of the problem where all categories are known a priori. To address these operational issues, this paper formalizes and presents steps towards the problem of open world recognition. The key steps of the problem are summarized in Fig. 1.

As noted by [34], “when a recognition system is trained and is operational, there are finite set of known objects in scenes with myriad unknown objects, combinations and configurations – labeling something new, novel or unknown should always be a valid outcome.” One reason for the domination of “closed world” assumption of today’s vision systems is that matching, learning and classification tools have been formalized as selecting the most likely class from a closed set. Recent research [34, 33, 15], has re-formalized learning for recognition as open set recognition. However, this approach does not explicitly require that inputs be as known or unknown. In contrast, for open world recognition, we propose the system explicitly label novel inputs as unknown and then incrementally incorporate them into the classifier. Furthermore, open set recognition as formulated by [34] is designed for traditional one-vs-all batch learning scenario. Thus, it is open set but not incremental and does not scale gracefully with the number of categories.

While there is a significant body of work on incremental learning algorithms that handle new instances of known classes [3, 4, 45], open world requires two more general and difficult steps: continuously detecting novel classes and when novel inputs are found updating the system to include these new classes in its multi-class open set recognition algorithm. Novelty detection and outlier detection are complex issues in their own right with long histories [26, 14] and they are still active vision research topics [2, 25]. After detecting a novel class, the requirement to add new classes leaves the system designer with the choice of re-training the entire system. When the number of categories are small, such a solution may be feasible, but unfortunately, it does not scale. Recent studies on ImageNet dataset using SVMs or CNN require days to train their system [30, 17], e.g. 5-6 CPU/GPU days in case of CNN for 1000 category image

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Table of Contents Towards An Open World Economy

1. Understanding the eBook Towards An Open World Economy
 - The Rise of Digital Reading Towards An Open World Economy
 - Advantages of eBooks Over Traditional Books
2. Identifying Towards An Open World Economy
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Towards An Open World Economy
 - User-Friendly Interface
4. Exploring eBook Recommendations from Towards An Open World Economy
 - Personalized Recommendations
 - Towards An Open World Economy User Reviews and Ratings
 - Towards An Open World Economy and Bestseller Lists
5. Accessing Towards An Open World Economy Free and Paid eBooks
 - Towards An Open World Economy Public Domain eBooks
 - Towards An Open World Economy eBook Subscription Services
 - Towards An Open World Economy Budget-Friendly Options
6. Navigating Towards An Open World Economy eBook Formats

- ePub, PDF, MOBI, and More
 - Towards An Open World Economy Compatibility with Devices
 - Towards An Open World Economy Enhanced eBook Features
7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Towards An Open World Economy
 - Highlighting and Note-Taking Towards An Open World Economy
 - Interactive Elements Towards An Open World Economy
 8. Staying Engaged with Towards An Open World Economy
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Towards An Open World Economy
 9. Balancing eBooks and Physical Books Towards An Open World Economy
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Towards An Open World Economy
 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
 11. Cultivating a Reading Routine Towards An Open World Economy
 - Setting Reading Goals Towards An Open World Economy
 - Carving Out Dedicated Reading Time
 12. Sourcing Reliable Information of Towards An Open World Economy
 - Fact-Checking eBook Content of Towards An Open World Economy
 - Distinguishing Credible Sources
 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
 14. Embracing eBook Trends
 - Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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