Simulating Historical Degradations for Enhanced Image Retrieval in Newspaper Archives

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1 Introduction

Historical newspaper archives serve as invaluable visual repositories of the social, cultural, and political landscapes of their times. These archives provide unique insights into historical events, trends, and daily life, enabling researchers and historians to study the past. However, the preservation and analysis of images within these publications present significant challenges due to various forms of image degradation caused by historical printing processes, physical aging, and environmental factors.

Images from newspapers of previous centuries are often characterized by deteriorations arising from techniques such as halftoning, rotogravure, and paper wear. These degradations manifest as artifacts, distortions, and loss of detail, which hinder the ability of researchers to accurately identify, classify, and trace the circulation of images across different publications and archival collections. For example, the repetitive patterns introduced by halftoning—a printing technique widely used in historical newspapers—can obscure fine details, while the grainy, high-contrast results of rotogravure create further challenges in image restoration and retrieval. Combined with the natural aging effects of paper, including folds, stains, and texture changes, these degradations make it difficult to extract meaningful information from historical images using traditional methods.

While significant research has been conducted in the domain of image restoration, aiming to reverse these degradations, there remains a critical gap in the simulation of historical degradations for the purpose of improving image retrieval systems. The ability to accurately simulate these degradation types offers a novel way to enhance the training of machine learning models, enabling more robust similarity computations and more effective identification of historical images. Such simulations are particularly valuable for tasks like image matching and retrieval within large-scale digital collections, such as those available in the Gallica Digital Library [5], which contain extensive archives of digitized historical newspapers.

The goal of this project is to bridge this gap by developing a library to simulate common degradation types observed in historical newspapers. Specifically, the project focuses on implementing techniques to mimic halftoning, noise, and aging effects, replicating the visual characteristics of degraded images. By doing so, this project aims to enhance data augmentation pipelines, providing enriched datasets for applications in historical image analysis. The goal of these simulated degradations is not only to improve the performance of similarity-based image retrieval systems but also to enable researchers to test and validate image restoration algorithms under realistic conditions.

Beyond technical contributions, enhanced retrieval systems can assist historians and archivists in tracing the circulation of images across newspapers, uncovering patterns of image reuse and distribution over time. This, in turn, supports the study of cultural and media history, offering deeper insights into how visual information was disseminated in the past. In short, this project aims to simulate key image degradation types observed in historical newspapers, bridging the gap between image restoration and retrieval.

2 Bibliography

2.1 Historical Context of Printing and Degradation Techniques

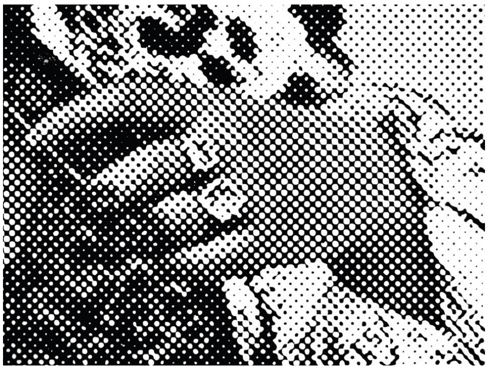
The historical evolution of printing techniques has played a pivotal role in shaping the preservation and analysis of visual media in newspaper archives. Understanding the origins and characteristics of printing methods such as halftoning and photogravure is essential to comprehending the degradation patterns that have developed over time. This section discusses the technical and cultural significance of these processes, exploring their impact on visual culture.

The Atlas of Analytical Signatures of Photographic Processes [9] focuses on documenting and analyzing historical printing methods such as halftoning and photogravure, which played critical roles in mass image reproduction.

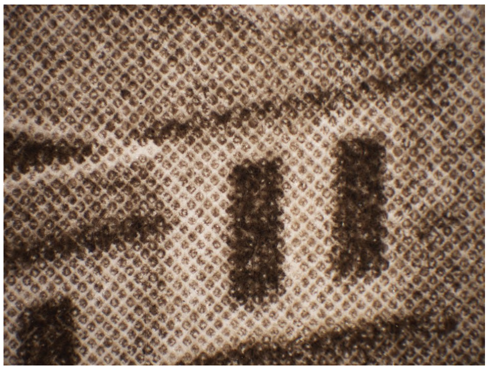
Halftoning is a technique used to reproduce continuous-tone images through the strategic placement of small dots of varying sizes. This transformation allows images to appear as though they contain a full range of tones when viewed from a distance, despite only using black and white ink. The process dates back to key contributors such as William Henry Fox Talbot and Frederic Ives, and it played a pivotal role in mass image production for newspapers, magazines, and books. Halftoning's ability to create the illusion of continuous tones by varying the size and spacing of dots made it an essential method for achieving high-volume, economical reproductions in print media. The Atlas Halftone [16] study employs historical analysis, visual inspection, and examination to categorize the distinct dot patterns and their application in various print types. This work provides a valuable reference for identifying halftone prints and understanding their evolution within the broader context of print reproduction.
Photogravure, on the other hand, represents a high-quality image reproduction process that dates back to the 19th century. This technique involves etching an image onto a metal plate—typically copper—which is then inked and pressed onto paper. Unlike halftoning, photogravure offers a continuous tonal range, making it particularly well-suited for reproducing detailed photographic images. The Atlas Photogravure [17] explores photogravure through visual examinations, along with chemical analyses, to document its distinct characteristics, including plate marks, grain patterns, and material compositions. This comprehensive study aids researchers in identifying photogravure prints and tracing their historical development. Visualization of halftone and photogravure printing techniques can be seen in Figure 1.

Sarah Mirseyedi's "Side by Side: The Halftone's Visual Culture of Pragmatism" [11] explores the historical development of halftone printing and its cultural and semiotic significance in the late nineteenth and early twentieth centuries. The paper explores how the emergence of halftone reproduction reshaped visual culture, particularly in illustrated magazines and newspapers, and its relationship with photography.

The study employs a historical and semiotic analysis, drawing on examples from illustrated press materials, philosophical discourse, and visual comparisons of halftone images alongside older methods like wood engravings. By placing halftones within a broader cultural and intellectual context, this study emphasizes their role in mass media visual culture. This paper is relevant to the project as it provides a deeper understanding of the historical and cultural nuances of halftone printing, which is essential for accurately



(a) Detail of a Halftone print example.



(b) Detail of a Rotogravure print example.

Figure 1: Visualization of halftone and rotogravure printing taken from [16], [17].

simulating and analyzing historical image degradation and retrieval.

The paper "Characterization of Prints Based on Microscale Image Analysis of Dot Patterns" [3] investigates the use of dot pattern characteristics as unique fingerprints to differentiate between original and reprinted documents. The study specifically focuses on analyzing rotogravure-printed samples on aluminum foil substrates at a microscopic scale. By leveraging a novel image processing pipeline, the authors automatically segment individual dots, extract distinct pattern features such as area, convexity, circularity, and classify dots into six different types, including doughnut-shaped patterns. Statistical analysis is then used to characterize the distribution and structure of these dots.

This approach offers valuable applications in the identification and authentication of printed products. However, the technique relies on precise imaging conditions and may face challenges in cases where dot patterns exhibit extreme variability or complex interactions with substrates. This paper's focus on dot-level analysis offers insights for projects aiming to simulate or understand degradation effects stemming from printing processes, making it relevant for historical document preservation.

2.2 Simulation and Analysis of Degradation Techniques

This section focuses on methodologies and techniques used to replicate and analyze common degradation patterns observed in historical documents and prints. It is important to mention that, while significant progress has been made in the restoration of degraded images, relatively few studies have focused on simulating degradation for the purpose of improving image retrieval. Of the limited research in this area, much of the work concentrates on halftoning techniques, often relying on specific filters and approaches that have not been thoroughly tested across diverse datasets. This leaves a critical gap in understanding other printing and degradation methods and their impacts on historical image analysis and retrieval accuracy.

The paper "A Survey of Techniques for the Display of Continuous Tone Pictures on Bilevel Displays" [7] reviews and analyzes various methods used to represent continuous-tone images on bilevel displays. The study focuses on converting continuous-tone still images into a series of bright and dark states on a pixel-by-pixel basis, thereby simulating the perception of continuous tones through precise control of spatial density. While halftoning is one method to achieve this, methods discussed include ordered dithering, constrained average, dynamic thresholding, and minimized average error algorithms, each of which handles the conversion of continuous tone differently.

Despite being published in 1976, this work remains highly relevant and contributes significantly to understanding how continuous-tone images can be rendered in binary form without sacrificing too much visual detail. By examining techniques that provide effective representation of image details, such as edge emphasis, this survey highlights the technical strengths and trade-offs inherent in each approach.

2.2.1 Halftoning Techniques

Error diffusion is a digital halftoning technique used to convert continuous-tone images into binary images (or other limited-tone representations) by distributing quantization errors to neighboring pixels. Several classic halftoning techniques have been developed to achieve different visual effects, particularly in historical printing and digital image processing.

Floyd-Steinberg and Atkinson dithering are two widely used error diffusion techniques. Floyd-Steinberg dithering is an algorithm published in 1976 [13], it distributes the quantization error to neighboring pixels in a serpentine scanning order, producing smooth tonal transitions. Atkinson dithering, originally developed for early Macintosh computers by Bill Atkinson, uses a smaller diffusion matrix, leading to a lighter and less pronounced dithering effect.

Bayer's ordered dithering, unlike error diffusion, applies a fixed threshold matrix to determine dot placement. This method creates structured, repeating patterns that are often used in early digital displays and printing.

Dot-based halftoning mimics traditional newspaper printing, where dot size is adjusted based on local intensity to simulate different shades. It works by dividing the image into blocks and replacing each block with a dot size proportional to the local intensity.

Each of these techniques plays a crucial role in historical and modern halftoning applications, offering distinct visual characteristics and trade-offs between detail preservation and computational complexity.

Apart from these classic methods, there has been research exploring alternative approaches to halftoning, including more advanced techniques. In 1997, "A Multiscale Error Diffusion Technique for Digital Halftoning" [8] presented an innovative approach to digital halftoning through a multiscale error diffusion algorithm. The technique utilizes an image quadtree representation of the error image between the input gray-level image and the output halftone image, facilitating an iterative process of dot placement guided by maximum intensity. By applying error diffusion in a multiresolution framework, the algorithm diffuses quantization error noncausally, both locally and globally, to achieve high-quality halftone reproduction.

One of the key contributions of this work is its ability to improve halftone image quality by reducing artifacts and enhancing edge details while avoiding the accumulation of quantization errors. However, a disadvantage is that the computational complexity of the algorithm is higher than simpler error diffusion methods due to its use of quadtree representation and multiresolution processing.

"Halftoning via Error Diffusion Using Circular Dot-Overlap Model" [21] introduces a model-based halftoning method that uses a circular dot-overlap printer model combined with error diffusion techniques to improve the accuracy of gray level reproduction in printed images. The primary objective of this approach is to accurately simulate how printers create overlapping circular dots, which often results in darker perceived gray levels due to dot gain. By integrating a modified model-based error diffusion method that incorporates edge enhancement, the authors aim to minimize gray-level biases and improve image detail retention.

The main contribution of this work is a refined model-based halftoning approach that accurately reproduces gray levels and maintains image detail. However, one disadvantage of this technique is that it may introduce complexity in real-time printing scenarios due to the need for precise computations and control over dot overlap, potentially increasing computational demands.

Aissi et. al. explore the application of artificial intelligence tools and data modeling techniques to analyze large collections of historical photographs, with a particular focus on early conflict photography from 1890-1918 in "Computer Vision, Historical Photographs, and Halftone Visual Culture" [1]. This work seeks to use both visual and textual data to study the development and circulation of historical images reproduced using halftone printing.

One of the key parts of this study is the simulation of halftone images and their integration into widely used datasets, such as ImageNet, by creating augmented versions of the data to improve feature robustness and visual similarity calculations. A few images from the ImageNet dataset they transformed into half-tone representations can be seen in Figure 2 This pre-training step enhances the ability of convolutional neural networks to identify and compare historical photographs with halftone representations more accurately. This approach is highly similar to the goal of this project, which focuses on simulating historical degradations to improve the retrieval and analysis of historical images.

Figure 2: Resulting half-tone representations of ImageNet images in "Computer Vision, Historical Photographs, and Halftone Visual Culture" [1]

2.2.2 Film Grain

The paper "Simulating Film Grain Using the Noise-Power Spectrum"[15] introduces a method for simulating film grain based on its noise-power spectrum to generate synthetic grain fields that closely approximate the characteristics of real film grain across various densities and magnifications. Film grain, which can add a visually appealing texture to images or introduce challenges during digital image processing, is modeled using the noise-power spectrum.

The implementation involves generating a white noise field transformed via a Fourier filter to match the desired noise spectrum and then integrating this grain pattern with images. Although this study does not focus explicitly on historical photographs, its techniques offer valuable potential for simulating the noise patterns often found in old photos.

2.2.3 Ink Fading and Diffusion

"Degradation Modeling and Prediction of Ink Fading and Diffusion" [19] develops a framework for modeling and predicting the degradation of printed images due to ink fading and diffusion, focusing primarily on halftone printing. The authors propose a multilayered degradation transition diagram that captures the dynamics of ink fading and diffusion in a complex, multi-ink environment.

This work provides detailed predictive model for ink degradation that accounts for factors such as overlapping ink states and environmental influences, improving understanding of long-term printed image stability. This approach is useful for applications in preserving historical documents, printed artwork, and archival materials. However, one disadvantage of the model is the numerous parameters required for accurate predictions, which can be impractical to tune for different data.

2.3 Image Restoration Techniques

While there exists a high amount of research dedicated to the restoration of degraded images, this project primarily focuses on the simulation of degradation rather than their restoration. Therefore, the report does not exhaustively cover restoration techniques but highlights a select few that are particularly relevant to historical image processing. Understanding these methods can still offer valuable insights for simulating degradation by illustrating how modern restoration techniques address and reverse complex visual artifacts.

2.3.1 Deep Learning-Based Restoration

This section explores two methodologies focused on the restoration of degraded historical photographs using advanced deep learning techniques. Gao et al.'s "Deep Restoration of Vintage Photographs From Scanned Halftone Prints" [6] presents a two-stage deep learning framework tailored to restoring vintage halftone prints. This technique divides the restoration process into two stages: first, a network removes blemishes and printing artifacts from real halftone prints using unsupervised learning, making them resemble clean synthetic halftones. The second stage applies a neural network trained on synthetic data to perform inverse halftoning, effectively transforming the enhanced halftone images back into continuous-tone images. This method achieves impressive results, significantly surpassing traditional approaches in reducing artifacts and restoring detail. The work emphasizes the challenge of handling compounded degradation in historical halftone images.

As another approach, Wan et al.'s "Bringing Old Photos Back to Life" [18] employs a triplet domain translation network to address complex, mixed degradation often seen in old photographs, such as scratches, blurring, and fading. The restoration process operates within a latent space formed by variational autoencoders (VAEs), aligning the latent representations of real and synthetic images to minimize domain gaps. The method's focus on simultaneously addressing various forms of degradation using domain translation and a flexible architecture offers a robust solution for restoring old photographs. Understanding these approaches to handling mixed degradation provides valuable insights for simulating realistic degradation patterns in historical images, aligning with the goals of this project.

2.3.2 Suppression of Noise

The paper "Suppression of Noise in Historical Photographs Using a Fuzzy Truncated-Median Filter" [20] introduces fuzzy filters specifically designed to reduce complex noise in historical photographs, such as cracks and graininess from physical aging. By employing two novel fuzzy filters, the method balances noise suppression and detail preservation through fuzzy membership functions blending median and moving average filtering techniques. This approach is particularly relevant for historical image projects, offering targeted solutions for the unique noise patterns found in aged photographs.

2.4 Machine Learning and Computer Vision Approaches for Historical Image Analysis

It is important to recognize how simulating degradation can contribute to the broader domain of historical image analysis. Machine learning and computer vision approaches have proven invaluable for extracting contextual information, classifying images, and conducting in-depth analyses of historical photographs. By improving the accuracy and robustness of image retrieval through degradation simulation, this work supports and complements efforts in historical image analysis. This section highlights contributions and methods that use machine learning and computer vision to analyze historical photographs.

The work of Chumachenko et al., in their "Machine Learning-Based Analysis of Finnish World War II Photographers" [2], exemplifies how state-of-the-art neural networks can illuminate the characteristics of photographers based on historical photo collections. By analyzing images from the Finnish Wartime Photograph Archive, the study classifies photographers using object detection and photo framing techniques. Through this approach, machine learning not only helps with distinguishing individual photographers but also provides insights into their historical significance. The demonstrated potential for automated tagging and similarity analysis significantly reduces manual labor for historians, making large-scale photo analysis more efficient and enriching the context for historical studies.

Extending the capacity for contextual understanding, Du et al.'s "Probing Historical Image Contexts through Computer Vision" [4] emphasizes the use of computer vision methods to trace the circulation and dissemination of historical images in printed media, particularly during the Second Sino-Japanese War. By using machine learning models like YOLO and ensemble approaches involving Vision Transformers, the study accurately correlates and retrieves context from historical archives. The approach highlights the editorial and propaganda strategies of wartime magazines, showing how computational analysis can help discover nuanced historical narratives.

Wevers and Smits explore the "Using Neural Networks to Study Historical Images" [14], focusing on the use of convolutional neural networks (CNNs) to categorize and analyze visual trends in digitized Dutch newspapers. Their work demonstrates how CNNs can classify and analyze large image archives, identifying shifts between illustrations and photographs over time. This deep learning-driven approach facilitates the exploration of visual trends, making it possible to conduct large-scale historical visual analyses that is manually infeasible.

Collectively, these studies underscore how machine learning and computer vision techniques elevate historical image analysis. Such research provides the broader analytical context that this work contributes to and supports.

2.5 Datasets and Benchmarking

Dataset availability is critical in the analysis and retrieval of historical photographs and documents. For a project centered on simulating degradations, such datasets not only serve as a crucial testing ground but also help discovering the realistic modeling of historical conditions, offering insights into how degradations impact retrieval and recognition tasks. The Gallica Digital Library [5] serves as an exemplary digital repository, offering a vast collection of digitized historical newspapers, including Le Petit Parisien prints. This library provides invaluable resources for researchers and historians by offering access to such comprehensive historical records.

Another example is The Newspaper Navigator Dataset [10], which aims to unlock the visual content embedded within 16 million pages of historic American newspapers digitized as part of the Chronicling America initiative. The dataset, developed using a fine-tuned visual content recognition model, extracts and categorizes various visual elements, including photographs, maps, and editorial cartoons. This large-scale visual content extraction supports new possibilities for historical image retrieval and contextual analysis, demonstrating the role of deep learning in transforming the accessibility of historical archives.

In addition, A Survey of Historical Document Image Datasets [12] presents a comprehensive review of datasets focused on historical document analysis, summarizing existing resources and identifying critical gaps in dataset diversity, representation, and standardization. The study categorizes datasets by tasks such as document classification, layout analysis, and content analysis, offering an essential overview for researchers working in the field. This review highlights the challenges inherent in analyzing diverse and degraded historical documents, emphasizing the need for more inclusive and standardized datasets.

Le Petit Parisien

ÉDITION DE PARIS

50 cent.

JEUDI 17 OCTOBRE 1940

LONDRES "Dévastations inimaginables" annonce Berlin

LA MYSTERIEUSE DISPARITION DE L'ATTACHÉ D'AMBASSADE

Le retour au foyer...

THÉRÈSE BLONDEAU

Dans une pharmacie qu'il avait rouverte A ORLÉANS UN FOU débitait des poisons violents

LE SCANDALE DE L'HOPITAL D'ORSAY Le coup de théâtre ne s'est pas produit...

Il est facile de rouler

Nouvelles heures du marché des Halles

LE COMMUNIQUE ALLEMAND

LE RAVITAILLEMENT

LES ÉLECTIONS PRÉSIDENTIELLES AUX ÉTATS-UNIS

CARBURANT

Source gallica.bnf.fr / Bibliothèque nationale de France

Figure 3: 17 October 1940 Le Petit Parisien print, taken from Gallica Digital Library.

3 Dataset

The dataset used in this project consists of 400 digitized negatives provided by the **Archives Nationales de France**, specifically from the historical newspaper collection of *Le Petit Parisien*. These images correspond to newspaper editions from October 8 to November 15 1940, covering various subjects such as public events, sports, and social affairs.

3.1 Size and Resolution

The images are high-resolution scans, with an average resolution of approximately 5000 $\times$ 4000 pixels.

3.2 Type of Images and Degradations

The dataset consists of historical photograph negatives, meaning that the scanned pages contain artifacts from both the original printing process and the digitization process.

- **Newspaper-Specific Degradations**: These include halftoning patterns, noise, ink bleed, paper aging, and other imperfections inherent to early 20th-century printing methods.
- **Scanning Artifacts**: The digitization process introduces additional degradations, such as blurriness, uneven lighting, dust specks, compression artifacts, and occasional cropping errors. These are not part of the original prints but affect the quality of the digital dataset.

The presence of both types of degradations presents a challenge, as some artifacts originate from historical printing while others are caused by modern scanning limitations. For the scope of this project, we focus on the newspaper-specific degradations.

3.3 Preprocessing

To make the dataset compatible with the degradation simulations, several preprocessing steps were applied:

- **Grayscale Conversion**: Images were converted to grayscale to simplify processing.
- **Histogram Equalization**: Applied to enhance contrast and improve visibility of fine details.
- **Downscaling & Upscaling**: Some experiments required resizing images to reduce computational costs while preserving essential structures, which were upscaled back to their original size after applying the chosen method. However, it is improtant to note that this is an optional preprocessing that the user can disable.

3.4 Visualization

To illustrate the nature of the dataset and the degradations present, Figure 4 presents a side-by-side comparison of images from the dataset alongside their corresponding newspaper prints, which were found manually by searching through archival records. Due to the manual nature of this process, only a small number of examples are provided, as locating exact matches required reviewing newspaper editions from the given date range one by one. This limitation highlights the importance of projects like this, which aim to develop automated methods for identifying and retrieving historical images without the need for exhaustive manual searches. This visualization further demonstrates the differences between the scanned negatives and the final printed versions, emphasizing the impact of historical printing techniques and the need for computational approaches in archival research.

(a) Scanned dataset image

RENTRÉE DE L'ANCIEN CHAMPION OLYMPIQUE DIMANCHE A WAGRAM

Jean Despeaux a conservé sa forme

en faisant des exhibitions ...et du crawl

ple, en plus de Degrauw, à qui nous accordons une revanche, Beslay, Marcel Tasart, Corsin ou Miellot. Chacun d'eux est susceptible de devenir un homme de premier plan en attendant le rétablissement définitif de Tenet. J'ai appris par le Petit Parisien qu'il avait repris le chemin de la salle, bien que son traitement à l'hôpital ne soit pas terminé. Il a du cran !

J'attends la réunion de dimanche avec impatience, conclut Dupré, car je n'ai pas vu boxer Jean depuis un an !

(b) Printed newspaper equivalent, Le Petit Parisien, October 11th 1940

(c) Scanned dataset image

Bagages à domicile

OU L'ON VOIT QUE LE CHEVAL...

(d) Printed newspaper equivalent, Le Petit Parisien, October 11th 1940

(e) Scanned dataset image

(f) Printed newspaper equivalent, Le Petit Parisien, October 20th 1940

Figure 4: Comparison of scanned images from the dataset (left) and their corresponding printed newspaper equivalents (right) collected from Gallica archives of Le Petit Parisien [5].

4 Modular Library Setup

The degradation simulation framework was designed with a modular architecture to ensure scalability, reusability, and ease of experimentation. The structure allows different degradation methods to be implemented independently while maintaining a unified workflow for applying them.

4.1 Folder Structure

The project is organized into separate directories for datasets, degradation methods, utility functions, and notebooks for testing. The main components are:

- **datasets/** – Contains original scanned images[1] and degraded outputs.
- **methods/** – Houses different categories of degradation algorithms:
  - **halftoning/** – Includes Floyd-Steinberg, Atkinson, Bayers threshold and dot-based halftoning methods.
  - **noise/** – Implements Gaussian noise, salt-and-pepper noise, and film grain.
  - **paper_effects/** – Simulates ink bleed and crumpled paper effects.
- **utils.py** – Contains helper functions for image processing, resizing, and saving outputs.
- **apply_degradation.py** – A script to apply a single degradation method to an image.
- **apply_pipeline.py** – Applies a sequence of degradations in a predefined order.
- **notebooks/** – Jupyter notebooks for testing individual methods and visualizing results.
- **venv/** – The virtual environment containing all dependencies.

4.2 Design Logic

The modular design follows a functional approach, where each degradation method is implemented as a separate function. This allows:

- Independent testing of each degradation method.
- Combining multiple degradations in a pipeline without modifying individual scripts.
- Ensuring reusability of functions across different experiments.

Since each method has different parameters, the pipeline script was designed to handle function calls dynamically, although some further optimization is needed to make parameter passing more consistent across all methods.

[1] Does not contain all 400 negatives, just selected negatives for testing, can be modified.

4.3 How to Use

4.3.1 Applying a Single Degradation

To apply a single degradation, users import the corresponding function from the relevant module and call `apply_degradation` with the appropriate parameters.

For example, to apply Floyd-Steinberg halftoning, the following code can be used:

```
from methods.halftoning.floyd_steinberg import floyd_steinberg_halftoning
from apply_degradation import apply_degradation

downscale_factor = 0.5 #optional

apply_degradation(
    method=floyd_steinberg_halftoning,
    input_path=input_path,
    output_folder=output_folder,
    downscale_factor= downscale_factor,
    block_size=8 # method specific parameter
)
```

For applying a different method, users simply change the import statement and adjust any method-specific parameters accordingly if they do not wish to use default parameter settings for each method.

4.3.2 Special Case: Film Grain

Most degradation methods are implemented in a standardized manner and can be applied using the `apply_degradation` function. However, the **film grain effect**, sourced from an external GitHub repository [2], follows a different structure and requires a separate implementation.

Due to its dependency on an external library, it does not fit directly into the unified degradation framework. Instead, it is applied through a dedicated script with parameters configured separately. Further details on its implementation are discussed in the Noise Implementation section 5.2.

4.3.3 Applying a Degradation Pipeline

The pipeline function allows users to sequentially apply multiple degradations, ensuring a structured and reproducible approach. It supports applying halftoning, noise, and paper effects, each with customizable parameters.

An example of how to use the updated pipeline:

```
# Example pipeline
final_image_path = apply_pipeline(
    input_path=input_image_path,
    output_folder=output_folder,
```

[2] https://github.com/larspontoppidan/filmgrainer

```
    halftoning_method=floyd_steinberg_halftoning,
    noise_method=add_gaussian_noise,
    paper_method=ink_bleed,
    halftoning_args={"block_size": 8},
    noise_args={"mean": 0, "stddev": 10},
    paper_args={"intensity_range": (0.4, 0.7)},
    downscale_factor_halftone=0.70,
    downscale_factor_noise=1.0,
    downscale_factor_paper=1.0
)
print(f"Pipeline complete. Final image saved at: {final_image_path}")
```

This implementation allows users to:

- Choose a halftoning, noise, and paper effect method from the available functions.
- Pass method-specific arguments through dedicated dictionaries.
- Adjust downscaling factors independently for each degradation stage.

Note: The *film grain effect* remains an exception due to its reliance on an external library. It follows a separate implementation and is not integrated into the pipeline in the same way as the other methods.

Jupyter notebooks in the `notebooks/` folder can also be used for testing and visualization, allowing users to apply degradations interactively and compare results.

5 Implementation of Methods

The following subsections detail the implementation of each degradation category, explaining the techniques used.

Each category of degradation replicates a specific aspect of historical printing and aging processes:

- **Halftoning Methods** – Simulate the printing techniques used in newspapers to approximate grayscale tones using discrete dots.
- **Noise Methods** – Introduce visual distortions commonly seen in scanned or aged documents, such as grain and speckling.
- **Paper Effects** – Replicate physical degradation, such as ink bleed and paper creases, caused by time and printing conditions.

Figure 5 shows the organization of implemented methods.

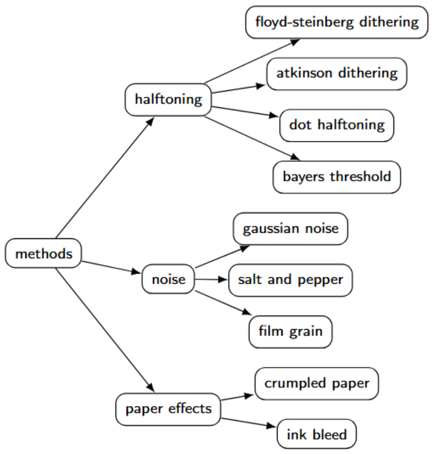


Figure 5: Graph of Implemented Methods

5.1 Halftoning Methods

In this project, four halftoning techniques were implemented: Floyd-Steinberg dithering, Atkinson dithering, Bayer's ordered dithering, and dot-based halftoning. Each method follows a different mathematical principle to achieve the halftone effect and has been implemented in a way that aligns with the modular structure of this project.

5.1.1 Floyd-Steinberg Dithering

Floyd-Steinberg dithering is an error diffusion algorithm that processes an image pixel by pixel, distributing the quantization error to neighboring pixels to maintain overall image tone. The main principle is:

$$I'(x,y) = \begin{cases} 0, & \text{if } I(x,y) < T \\ 1, & \text{if } I(x,y) \geq T \end{cases}$$

where $I(x, y)$ is the grayscale intensity of the pixel at (x, y), $I'(x, y)$ is the binarized pixel, and T is a threshold (usually 128 for an 8-bit image). The quantization error is calculated as:

$$E = I(x, y) - I'(x, y)$$

This error is distributed to neighboring pixels according to the Floyd-Steinberg diffusion matrix:

$$\frac{E}{16}\begin{bmatrix} 0 & x & 7 \\ 3 & 5 & 1 \end{bmatrix}$$

The Floyd-Steinberg dithering algorithm was implemented as a function that operates on grayscale images. Since this method relies on pixel-by-pixel processing, optimizations such as block-based processing were explored to improve efficiency on high-resolution images.

Results showed that Floyd-Steinberg dithering produces smooth gradients and realistic grayscale approximations, and downscaling the images before processing significantly reduces the computational time. Additionally, when images were downscaled before processing and then upscaled back to their original size, the halftoning effect became more pronounced, creating a coarser and more noticeable dithering pattern.

Figure 6 shows the results obtained by applying Floyd-Steinberg dithering with varying downscale parameters using block size of 8. The block size parameter implemented in Floyd-Steinberg and Atkinson dithering defines the processing granularity by dividing the image into smaller regions where the dithering algorithm is applied independently. Instead of propagating quantization error across the entire image, error diffusion is confined within each block. This approach helps improve computational efficiency. In the figure we can observe that with no downscaling applied, the affect of the method is almost not visible to the eye.

(a) Floyd-steinberg dithering with no downscale applied.

(b) Floyd-steinberg dithering after downscaling to %70.

(c) Floyd-steinberg dithering after downscaling to %30.

Figure 6: Comparison of the Floyd-steinberg dithering results with different levels of downscaling.

The resulting close-up affect of Floyd-steinberg with no downscaling can be seen in figure 7.

Figure 7: The close-up affect of floyd-steinberg dithering.

5.1.2 Atkinson Dithering

Atkinson dithering is another error diffusion method but with a different distribution matrix. Unlike Floyd-Steinberg, it spreads the error over a wider neighborhood with smaller values and disregards some of the error. The error distribution is:

$$\frac{E}{8}\begin{bmatrix} 0 & x & 1 & 1 \\ 1 & 1 & 1 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

Since Atkinson dithering diffuses less error per pixel, the resulting halftone pattern is more sharp and has more contrast, making it visually different from Floyd-Steinberg. Atkinson dithering was implemented using a similar error diffusion process as Floyd-Steinberg but with a different kernel distribution. The method was applied varyng level of downscaled images to evaluate its effectiveness similarly to Floyd-steinberg method. The result can be seen in Figure 8.

(a) Atkinson dithering with no downscale applied.

(b) Atkinson dithering after downscaling to %70.

(c) Atkinson dithering after downscaling to %30.

Figure 8: Comparison of the Atkinson dithering results with different levels of downscaling.

The resulting close-up affect of Atkinson with no downscaling can be seen in figure 9.

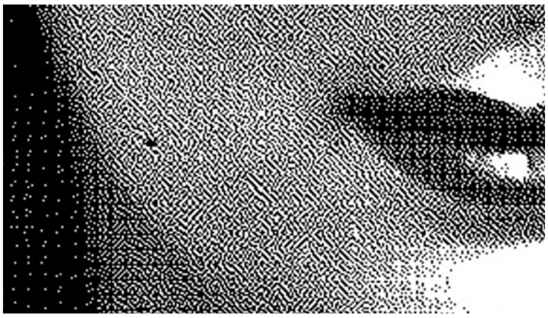


Figure 9: The close-up affect of Atkinson dithering.

5.1.3 Bayer's Ordered Dithering

Unlike Floyd-Steinberg and Atkinson dithering, which dynamically distribute errors, Bayer's ordered dithering applies a predefined threshold matrix to the image. The image is divided into $n \times n$ regions, and each pixel is compared against an ordered dithering matrix B_n. For a 2×2 Bayer matrix:

$$B_2 = \begin{bmatrix} 0 & 2 \\ 3 & 1 \end{bmatrix}$$

For each pixel (x, y), the threshold is determined by:

$$T(x, y) = \frac{255}{n^2 - 1} \times B_n(x \mod n, y \mod n)$$

If $I(x, y)$ is greater than $T(x, y)$, the pixel is set to white; otherwise, it is set to black. This creates a structured and repeatable halftone pattern that is computationally efficient but introduces visible artifacts in smooth areas. Bayer's dithering was implemented accordingly.

The result of applying Bayer's ordered dithering without downscaling and n=4 can be seen in following figure 10 with a comparison to the original image. Please see Figure 11 for a close up visual of Bayer's ordered dithering.

(a) Original image

(b) Bayer's ordered dithering

Figure 10: Comparison of the original image, Bayer's ordered dithering result, and a close-up view of the dithering effect.

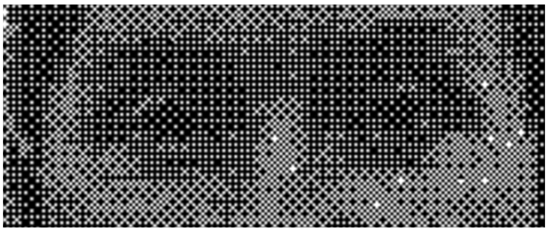


Figure 11: Close-up visualization of Bayer's ordered dithering

5.1.4 Dot-Based Halftoning

Dot-based halftoning simulates printing techniques by varying the size of dots rather than using dithering, in other words it clusters dots together instead of distributing errors. The process involves:

- Dividing the image into small square cells of size $n \times n$.
- Computing the average grayscale intensity I_{avg} of each cell.
- Determining the dot size based on a mapping function:

$$r = R_{\max}\left(1 - \frac{I_{\text{avg}}}{255}\right)$$

  where r is the radius of the dot and $R_{\max}$ is the maximum dot size.

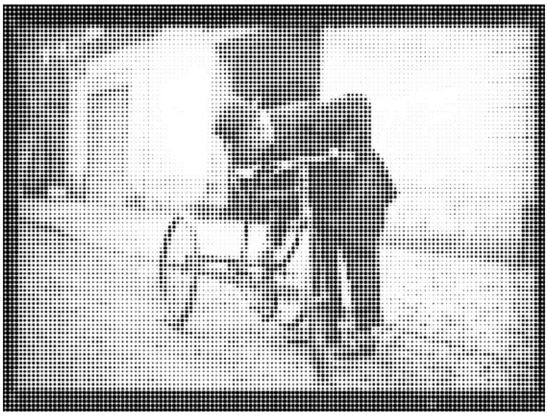
- Drawing a circle of radius r at the center of each cell.

The dot-based halftoning method was implemented using circle drawing operations over a grid. Since this approach works at the block level, it is more computationally efficient for high-resolution images than pixel-based dithering. However, it is not as tonally smooth as dithering methods, and loses fine details.

The results of this method are visually very different compared to previous methods and the resulting images are "cartoonish". Following figure 12 displays the result of dot-based halftoning compared to the original image, with different cell sizes.

(a) Original image

(b) Dot-based Halftoning with cell size 4x4.



(c) Dot-based Halftoning with cell size 32x32.

Figure 12: Dot-based halftoning results for different cell sizes.

5.2 Noise Methods

Noise is a common type of image degradation that occurs due to various factors such as sensor limitations, compression artifacts, and environmental conditions during scanning or printing. In historical newspaper images, noise often appears as grain, speckling, or random distortions, affecting image clarity. To simulate these degradations, three types of noise were implemented in this project: Gaussian noise, salt-and-pepper noise, and film grain.

5.2.1 Gaussian Noise

Gaussian noise is one of the most widely used models for representing natural noise in images. It follows a normal distribution:

$$P(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

where μ is the mean (center of the distribution) and σ is the standard deviation (controls the spread of noise). When applied to an image, each pixel value is modified by adding a random value sampled from this Gaussian distribution.

In this project, Gaussian noise was implemented by generating a noise matrix with values sampled from a normal distribution, which was then added to the original image. The noise level was controlled using two parameters:

- **Mean (μ)**: Determines the average intensity shift.
- **Standard deviation (σ)**: Controls the strength of the noise.

Lower values of σ produce subtle distortions, while higher values introduce significant graininess.

5.2.2 Salt-and-Pepper Noise

Salt-and-pepper noise is a type of impulse noise that appears as random white ("salt") and black ("pepper") pixels scattered throughout an image. It simulates real-world image degradations that can be caused by dust or scratches.

Mathematically, salt-and-pepper noise can be modeled as:

$$P(x) = \begin{cases} p, & x = 0 \text{ (black pixel)} \\ q, & x = 255 \text{ (white pixel)} \\ 1 - (p + q), & \text{original pixel value} \end{cases}$$

where p and q are the probabilities of black and white noise appearing in the image.

In this project, salt-and-pepper noise was applied by randomly selecting a fraction of pixels and setting them to either 0 (black) or 255 (white) based on a predefined noise probability.

5.2.3 Film Grain

Film grain is a type of noise that naturally occurs in analog photography and film processing, giving images a textured appearance. Unlike Gaussian noise, which is evenly distributed, film grain creates organic, irregular patterns.

Film grain was implemented by installing an external Github repository called filmgrainer [3].Instead of modifying individual pixel values, filmgrainer overlays a generated grain pattern onto the image, simulating the effect of aged photographic film. Unlike Gaussian or salt-and-pepper noise, this method does not rely on simple pixel-wise transformations but instead simulates the grain distribution seen in traditional film stock.

Due to its external dependency, film grain was not directly integrated into the pipeline like the other noise methods. Instead, it was applied separately in wrapper function using a command-line approach, requiring additional processing steps.

5.2.4 Visualization of Noise Effects

Figure 13 shows the results for each noise method implemented. These results were obtained without applying downscaling.

[3]https://github.com/larspontoppidan/filmgrainer

(a) Gaussian.

(b) Salt and pepper.

(c) Film grain.

Figure 13: Comparison of Noise methods.

5.3 Old Paper Effect Methods

In historical newspaper archives, image degradation is not limited to printing techniques and noise but also includes the physical aging of the paper itself. Over time, newspapers experience ink diffusion, creases, folds, and surface damage, which alter the appearance of printed images. To replicate these effects, two paper degradation methods were implemented: ink bleed and folding (crumpled paper simulation).

5.3.1 Ink Bleed

Ink bleed occurs when the ink spreads beyond its intended boundaries, often due to the absorption properties of the paper and the printing technique used. In aged newspapers, ink bleed makes text and images appear slightly smudged or blurred, reducing sharpness.

The ink bleed effect was implemented using the `Augraphy` [4] library with a wrapping function to keep the modularity. It provides an ink diffusion simulation based on random spread patterns. The main parameters controlled the intensity and spread range of the effect, allowing for different levels of ink absorption. However, even with high intensity, unfortunately the resulting effect is not easily visible to the eye when applied to images in this project's dataset, unless there is a high level of downscaling.

5.3.2 Folding (Crumpled Paper Effect)

Another common degradation in old newspapers is paper folding and crumpling, which introduces visible creases and texture deformations. In real-world historical documents, folds cause brightness variations, cracks, and distortions in both text and images.

The crumpled paper effect was also implemented using the Augraphy library, which provides a fold simulation feature. However, the results were highly suboptimal, as the

[4]https://augraphy.readthedocs.io/en/latest/

generated fold patterns appeared too artificial and lacked natural variations found in real folded paper. Realistic crumpled paper effects usually require:

- Mesh-based deformations – Simulating actual 3D surface bending and shading.
- Matlab-based implementations – More advanced modeling techniques exist in Matlab for paper deformation.
- Handcrafted texture overlays – Using real scanned textures of crumpled paper blended with the image.

Please see Figure 14 for the result of Augraphy's so-called paper crumpling method, which unfortunately does not provide a realistic effect.

Figure 14: Paper crumpling method by Augraphy.

6 Pipeline Implementation

The goal of this pipeline is to simulate historical newspaper image degradations by sequentially applying halftoning, noise, and paper effects to an input image. By combining multiple degradation techniques, the pipeline aims to recreate the visual characteristics of printed photographs found in historical newspapers.

6.1 Overview of the Design

The pipeline was designed to be modular and flexible, allowing users to select different degradation methods and customize their parameters. It allows users to experiment with different combinations of methods, fine-tune parameters, and adjust downscaling factors to achieve the most visually realistic results.

After experimenting with multiple configurations, one of the more visually convincing combination was: Floyd-Steinberg halftoning + Gaussian Noise + Ink bleed. However, the effectiveness of the pipeline depends on the characteristics of the input image. Despite achieving visually closer to newspaper results, the pipeline does not always produce consistent visual accuracy across all images. Some key challenges include:

- **No universal solution**: The optimal method combination varies depending on the image. While some images look more realistic after processing, others differ from the expected newspaper appearance.

- **Need for manual experimentation**: Users must adjust parameters, downscaling factors, and method selection to achieve the closest match to a specific historical newspaper image.

- **Dependence on image content**: Certain images, particularly those with high contrast or fine details, react differently to the degradations.

While the pipeline makes images get closer to the visual look of historical printing effects, further refinements could improve usability and automation.

6.2 Comparison with Real Newspaper Prints

To evaluate the effectiveness of the pipeline, processed images were compared with their equivalent photographs found in historical newspapers. Following Figures 15 and 16 present side-by-side comparisons, showing:

- The **original high-resolution photograph**.

- The **historical newspaper print equivalent**.

- The **simulated newspaper version** generated by the Floyd-Steinberg halftoning + Gaussian Noise + Ink bleed pipeline.

Additionally, it is important to note that some newspaper versions of the images appear to have undergone "editorial modifications" before publication. Upon close inspection, certain photographs show signs of manual alterations, such as:

- **Elements being removed or cropped out**: Some details visible in the original photograph are missing in the newspaper print, possibly to enhance focus or eliminate distracting elements.

- **Hand-drawn enhancements**: In some cases, extra lines or shading appear as if they were manually drawn over the image, likely to improve contrast or highlight certain features for better visibility in print.

- **Structural adjustments**: Some newspaper prints show signs of retouching, potentially to compensate for printing limitations or to highlight certain elements.

These modifications suggest that historical newspapers did not always use unaltered versions of photographs. Instead, editorial decisions played a role in how images were processed before being printed. This aspect further complicates the goal of simulating historical newspaper prints, as the pipeline can only recreate the printing degradations and not the manual artistic modification that were applied during the publication process.

(a) Original photograph

Bagages à domicile

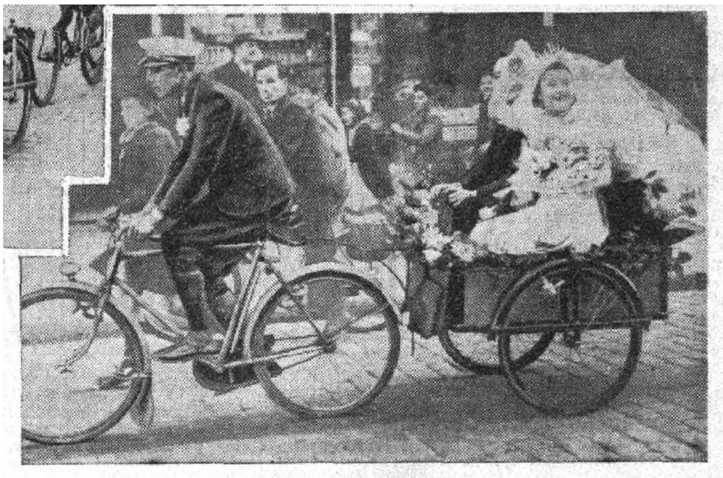
OU L'ON VOIT QUE LE CHEVAL...

(b) Newspaper print

(c) Simulated result

Figure 15: Comparison of an original image, its historical newspaper print, and the pipeline-generated simulation.

(a) Original photograph



(b) Newspaper print

(c) Simulated result

Figure 16: Comparison of an original image, its historical newspaper print, and the pipeline-generated simulation.

For reproducibility purposes, simulation on Figures 15 and 16 were created using the following pipeline parameters:

```
        final_image_path = apply_pipeline(
        input_path=input_image_path,
        output_folder=output_folder,
        halftoning_method=floyd_steinberg_halftoning,
        noise_method=add_gaussian_noise,
        paper_method=ink_bleed,
        halftoning_args={"block_size": 16},
        noise_args={"mean":0, "stddev":10},
        paper_args={},
        downscale_factor_halftone=0.6,
        downscale_factor_noise=0.1,
        downscale_factor_paper=0.7
    )
```

6.3 Future Improvements

While the pipeline is functional, it could benefit from:

- **Improved automation**: Reducing the need for manual parameter tuning by incorporating adaptive degradation selection.
- **Interactivity**: Allowing users to adjust and preview effects dynamically through a graphical interface.
- **Machine learning-based enhancement**: Training a model to predict the best degradation parameters based on input images.

These enhancements could make the pipeline more efficient and user-friendly, particularly for researchers working with large historical datasets.

7 Discussion and Limitations

While the pipeline is effective in simulating certain types of degradations, it has several constraints:

- **No automatic parameter selection:** Users must manually adjust method parameters, downscaling factors, and degradation strengths to achieve the best results. This makes the pipeline less efficient for large-scale use.
- **Limited realism for paper texture effects:** While ink bleed produced reasonable results, the crumpled paper effect was highly unrealistic. Existing implementations in Python did not provide convincing fold and crease textures, and more advanced approaches (e.g., 3D modeling or mesh deformation) would be required.
- **Variation in real-world newspaper prints:** Historical newspapers do not have a single uniform degradation pattern in printing techniques, ink quality, and paper type introduce variations that are difficult to model with a fixed pipeline.

- **Some degradations are not replicable:** The pipeline focuses on physical and printing-related degradations, but manual editorial modifications made to historical newspaper prints (such as hand-drawn retouching and contrast enhancements) cannot be simulated the same way.
- **Gray level differences between newspaper prints and digital grayscale:** It was challenging to fully replicate the perceived gray tones of historical prints using digital methods. Factors such as ink absorption, paper texture, and scanning artifacts further influence the appearance of grayscale in newspaper images.
- **Research Gap:** One of the biggest challenges in this project was the lack of prior research on degradation simulation. Current research in historical document processing is heavily focused on denoising, sharpening, and restoring degraded images to improve quality. There is significantly less work on intentionally recreating degradations. Since there are no widely accepted benchmarks for simulated degradation, it is challenging to evaluate the results.

8 Future Work

This project provides a structured approach to simulating historical newspaper degradations, but there are still areas for improvement. The pipeline works well for some images, but the results are inconsistent, and users must manually adjust parameters to get the best output. Future improvements should focus on **optimizing the pipeline, improving code efficiency, and expanding the range of degradation methods**.

Pipeline Optimization. One of the biggest challenges is that no single parameter set works for all images. Some processed images manage to more closely resemble real newspaper prints, while others do not. Users currently have to experiment with different methods and settings, which is time-consuming. A possible improvement would be to develop an **adaptive system** that automatically selects the best degradation settings based on the input image.

Another limitation is that the pipeline is not interactive. An improved version could provide **real-time previews** where users can adjust degradation parameters visually before finalizing their results. Additionally, incorporating a **machine learning-based degradation model** could automate parameter selection by learning from historical newspaper prints, such as implementing a type of automatic data augmentation.

Improving Modularity and Code Efficiency. The project was designed with a modular approach, but some functions still contain redundancies. The functions apply_degradation and apply_pipeline overlap in functionality, making the code less efficient. A more streamlined implementation would improve code reuse and maintainability. Standardizing function parameters across all degradation methods would also make it easier to apply different effects without manual adjustments.

Expanding Degradation Methods. The current pipeline includes halftoning, noise, and some paper effects, but more degradation types could help improve the realism of the results. Simulating **paper aging, ink misalignment, smudging, and**

additional historical printing styles would increase the diversity of effects. Since real newspaper prints often contain random imperfections, introducing these could make the results more authentic.

Achieving More Realistic Newspaper Simulations. Although some processed images resemble historical newspaper prints, the pipeline does not fully capture the complexity of old printing techniques. Newspapers were printed using different halftoning techniques, paper qualities, and ink properties, all of which influence their final appearance. Additionally, some newspaper prints were edited manually before publication, making it difficult to perfectly match their appearance using algorithmic degradations alone.

Another good direction for future work could be developing a systematic way to evaluate the accuracy of the simulated results, rather than relying only on visual comparisons.

9 Conclusion

The project results have managed to visually get closer to newspaper prints compared to original scanned images from the dataset, however it is far from perfect. Future improvements should focus on making the pipeline **more efficient, flexible, and realistic**. By refining the implementation, adding more degradation effects, and improving automation, the project could become a valuable tool for **simulating historical newspaper images**.

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