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EDUCATIONAL INNOVATION IN MEXICO: ENHANCING LEARNING WITH ARTIFICIAL INTELLIGENCE, APPLYING CHATGPT IN HIGHER EDUCATION INSTITUTIONS, PROFESSOR-STUDENT COLLABORATION

INNOVACIÓN EDUCATIVA EN MÉXICO: MEJORA DEL APRENDIZAJE CON INTELIGENCIA ARTIFICIAL, APLICACIÓN DE CHATGPT EN INSTITUCIONES DE EDUCACIÓN SUPERIOR, COLABORACIÓN PROFESOR-ESTUDIANTE

Pedro Jácome Onofre
Department of Industrial Engineering of the National Technology of Mexico

Jesús Manuel Orona Hinojos
Managing Director of Company Data Sc Consultancy Group – México

Guillermo Reyes Morales
Department of Mechatronic Engineering of the National Technology of Mexico, Campus San Andrés – México

Eduardo Macias Ávila
Manager Company Data Sc Consultancy Group. Duvhe – México

Alfonso Flores Leal
Department of Computer Systems Engineering of the National Technology of Mexico Campus Orizaba - México

Benjamin Alvarez Jimenez
Department of Electrical and Electronic Engineering of the National Technology of Mexico

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Educational Innovation in Mexico: Enhancing Learning with Artificial Intelligence, Applying ChatGPT in Higher Education Institutions, Professor-Student Collaboration

Pedro Jácome Onofre[1]
pedrojacome@itssat.edu.mx
https://orcid.org/0000-0003-3698-8893
Department of Industrial Engineering of the National Technology of Mexico
Campus SanAndrés Tuxtla
Veracruz, México

Jesús Manuel Orona Hinojos
jesus.orona@datasc-consultant.com
https://orcid.org/0000-0001-6416-1514
Managing Director of Company Data Sc Consultancy Group
Coahuila, México

Guillermo Reyes Morales
guillermoreyes@itssat.edu.mx
https://orcid.org/0000-0002-7341-3784
Department of Mechatronic Engineering of the National Technology of Mexico, Campus San Andrés Tuxtla
Veracruz,México.

Eduardo Macias Ávila
eduardo.macias@datasc-consultant.com
https://orcid.org/0000-0002-6438-1119
Manager Company Data Sc Consultancy Group. Duvhe
Coahuila, México.

Alfonso Flores Leal
alfonso.fl@orizaba.tecnm.mx
https://orcid.org/0009-0004-6207-6307
Department of Computer Systems Engineering of the National Technology of Mexico
Campus Orizaba
Veracruz México

Benjamin Alvarez Jimenez
benjamin.aj@orizaba.tecnm.mx
https://orcid.org/0009-0009-6995-1270
Department of Electrical and Electronic Engineering of the National Technology of Mexico
Campus Orizaba Veracruz, México

ABSTRACT

This study explores the integration of artificial intelligence, specifically ChatGPT, into higher education institutions in Mexico as a means of fostering educational innovation. The focus is on leveraging ChatGPT to enhance professor-student collaboration and improve the overall learning experience. The research delves into the implementation of ChatGPT in diverse academic settings to analyze its impact on student engagement, knowledge retention, and collaborative learning dynamics. The study employs a mixed-methods approach, combining quantitative data collection through pre- and post-implementation assessments, and qualitative insights gathered from interviews, surveys, and focus groups with both professors and students. By examining the perceptions and experiences of participants, the research aims to identify the strengths and challenges associated with integrating ChatGPT into the higher education program of studies in Mexico. The findings shed light on the effectiveness of ChatGPT in facilitating interactive and dynamic exchanges between professors and students. Additionally, the study investigates the role of ChatGPT in personalized learning experiences, addressing individual student needs and learning preferences. Ultimately, this study contributes to the discourse on educational innovation in Mexico by offering insights into the transformative potential of artificial intelligence, particularly ChatGPT, in higher education. Ultimately, this study contributes to the discourse on educational innovation in Mexico by offering insights into the transformative potential of artificial intelligence, particularly ChatGPT, in higher education. The outcomes of this research provide practical recommendations for institutions seeking to integrate AI technologies to active professor-student collaboration and improve the overall educational view.

Keywords: personalized learning, collaborative learning dynamics, homeschooling, innovation in mexico

[1] Autor Principal
Correspondencia: pedrojacome@itssat.edu.mx

Innovación educativa en México: mejora del aprendizaje con inteligencia artificial, aplicación de ChatGPT en instituciones de educación superior, colaboración profesor-estudiante

RESUMEN

Este estudio explora la integración de la inteligencia artificial, específicamente ChatGPT, en instituciones de educación superior en México como medio para fomentar la innovación educativa. El enfoque está en aprovechar ChatGPT para mejorar la colaboración entre profesores y estudiantes y mejorar la experiencia de aprendizaje en general. La investigación profundiza en la implementación de ChatGPT en diversos entornos académicos para analizar su impacto en el compromiso estudiantil, la retención de conocimientos y la dinámica del aprendizaje colaborativo. El estudio emplea un enfoque de métodos mixtos, combinando la recopilación de datos cuantitativos mediante evaluaciones previas y posteriores a la implementación, y percepciones cualitativas obtenidas de entrevistas, encuestas y grupos focales con profesores y estudiantes. Al examinar las percepciones y experiencias de los participantes, la investigación tiene como objetivo identificar las fortalezas y desafíos asociados con la integración de ChatGPT en el programa de estudios de educación superior en México. Los hallazgos arrojan luz sobre la efectividad de ChatGPT para facilitar intercambios interactivos y dinámicos entre profesores y estudiantes. Además, el estudio investiga el papel de ChatGPT en experiencias de aprendizaje personalizadas, abordando las necesidades individuales de los estudiantes y sus preferencias de aprendizaje. En última instancia, este estudio contribuye al discurso sobre la innovación educativa en México al ofrecer perspectivas sobre el potencial transformador de la inteligencia artificial, en particular ChatGPT, en la educación superior. Los resultados de esta investigación proporcionan recomendaciones prácticas para instituciones que buscan integrar tecnologías de IA para activar la colaboración profesor-estudiante y mejorar la visión educativa en general.

Palabras clave: aprendizaje personalizado, dinámicas de aprendizaje colaborativo, educación en el hogar, innovación en México

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INTRODUCTION

Educational systems worldwide are undergoing a transformative shift with the integration of artificial intelligence (AI) technologies. In Mexico, as in many other countries, the pursuit of educational innovation has become a focal point to enhance learning outcomes and prepare students for the challenges of the 21st century (Chiu, 2024). This study delves into the realm of AI, specifically the application of ChatGPT, in higher education institutions across Mexico, with a primary focus on fostering collaboration between professors and students. The motivation for this research stems from the recognition that traditional teaching methods are encountering challenges in meeting the diverse needs of modern learners. As students increasingly engage with digital technologies in their daily lives, the integration of AI into educational settings becomes not only relevant but imperative. Furthermore, the research is prompted by a genuine curiosity about how AI, and specifically ChatGPT, can transcend conventional boundaries to create a collaborative learning environment. The desire is to understand how this technology can act as a catalyst for increased student engagement, improved knowledge retention, and the establishment of a more interactive and personalized educational experience (Hallal et al., 2023). Traditional teaching methods often struggle to engage students who are accustomed to digital interactions in their daily lives. The existing educational paradigm may not fully capitalize on the opportunities presented by AI to create a more dynamic and personalized learning environment (Vera, 2023). This research aims to address this problem by investigating the efficacy of ChatGPT in enhancing professor-student collaboration and its impact on student engagement and knowledge retention. Furthermore, the problem statement encompasses the need to develop a nuanced understanding of the ethical considerations associated with the integration of AI in education (Vera, 2023). As AI technologies become more prevalent in higher education settings, there is a lack of comprehensive guidelines and best practices tailored to the Mexican context. This research seeks to identify and address these ethical considerations to ensure the responsible deployment of ChatGPT within academic institutions. The problem statement also acknowledges the potential challenges and barriers that may arise during the implementation of ChatGPT in higher education. These challenges could range from technical issues to resistance from educators or concerns related to data privacy. Understanding and mitigating these challenges are crucial for the successful adoption of AI technologies in the Mexican higher education landscape. Through this research, we aspire to contribute valuable insights that can inform educational policymakers, institutions, and educators in Mexico, providing practical recommendations for harnessing the potential of AI to enrich professor-student collaboration and elevate the quality of education in the country. As we navigate the intersection of technology and education, it is essential to strike a delicate balance that maximizes the benefits of AI while upholding the ethical standards that underpin effective and responsible educational practices.

Objectives

The objective is to understand how the integration of this artificial intelligence technology can positively impact student engagement, knowledge retention, and the overall quality of collaboration between teachers and students. And identify the strengths and challenges associated with ChatGPT integration.

Literature Review

The literature review on educational innovation in Mexico, particularly focusing on enhancing learning with artificial intelligence (AI) and applying ChatGPT in higher education institutions, with an emphasis on professor-student collaboration, can explore various dimensions of this dynamic field. Below is an outline that covers key aspects and potential themes for a comprehensive literature review:

Artificial Intelligence (AI) has emerged as a transformative technology in the scientific community with the potential to accelerate and improve research in various fields. ChatGPT, a popular language model is one of those AI-based systems that is increasingly being discussed and adapted in scientific research. However, as with any technology, there are challenges and limitations that need to be addressed. This article focuses on the empowerment that ChatGPT faces in the field of higher education research. This author mentioned This article will take organic materials as examples in the use of ChatGPT. Overall, this article aims to provide information on the challenges and limitations of researchers working at higher level (Cheng, 2023). Many researchers have quickly realized and discussed the future impacts of ChatGPT on scientific writing and publishing. However, how this open access AI tool can be used to facilitate technical research has not yet been explored as is the rationale. Problem posing in higher level work so that an academic work does not lack ideas, and above all interprets communication. This article will use ChatGPT as a model to demonstrate how this technique can help in scientific research (Cheng, 2023). Higher education is crucial to producing ethical citizens and professionals globally. The introduction of generative AI (GenAI), such as ChatGPT, has brought opportunities and challenges to the traditional education model. However, current conversations focus on policy development and evaluation, with limited research on the future of higher education. GenAI's impact on learning outcomes, pedagogy and assessment is crucial to reforming and advancing the academic workforce. This qualitative study aims to investigate students' perspectives on the impact of GenAI in higher education (Chiu, 2024).

How do ChatGPT and other forms of Generative Artificial Intelligence (GenAI) affect the way we have been conducting and evaluating academic research, teaching, and business practice? (Peres et al., 2023). Well, it doesn't affect us, the reality is that we focus our thoughts on other activities that ChatGPT cannot intervene in, for example, in practical activities, such as maintaining an engine, turning on and turning a part, or starting up some industrial equipment. I argue that ChatGPT and other generative artificial intelligence tools pose three main threats to our current education systems, creating problems of measurement, information accuracy, and skill devaluation. But when we place these threats into historical context, we see that AI tools can also empower students and level the educational playing field. In classrooms from primary to tertiary and spanning all content areas, we can help our students become critical thinkers by using ChatGPT to comprehend texts, aggregate knowledge, and understand genre conventions in prose as well as programming. The aim is to help students leverage AI as a tool that they question and critique, advancing their own comprehension, research, and composition skills in the process (Steele, 2023).

Innovating in teaching with ChatGPT

This is about making ChatGPT a trusted advisor for teachers and students at the higher level in this revolutionary ChatGPT technology that provides practical strategies to plan and execute more inclusive and effective classes. The research begins with the search for the research articles to be included in the study (Einarsson et al., 2024). This paper explores the potential of large language models, specifically ChatGPT, to reframe problems from probability theory and statistics, making them accessible to students across diverse academic fields including biology, economics, law, and engineering (Einarsson et al., 2024). The aim of this study is to enhance interdisciplinary learning by rendering complex concepts more accessible, relevant, and engaging.

Enhancing educational creativity

Findings could facilitate policymakers with insights into the determinants and initiate effective and efficient policies to improve artificial intelligence use in education, specifically ChatGPT. Artificial Intelligence (AI) and natural language processing have significantly impacted education, providing new opportunities for innovative teaching and learning practices. One of the significant breakthroughs in AI is the development of the Chat Generative Pre- Trained Transformer (ChatGPT), which can generate human-like text and conversationally respond to users' input (Habibi et al., 2023). ChatGPT has great potential to improve the quality and efficiency of learning practices, such as generating personalized content, helping with homework, and providing feedback to students (Lund & Wang, 2023). Text generation: ChatGPT can generate text in a specific style or tone, allowing researchers to easily generate draft versions of research papers, grant proposals and other written materials (Lund & Wang, 2023). Question answering: ChatGPT can be fine-tuned to provide answer to domain specific questions, making it a powerful tool for scholars to find answers quickly and efficiently.

ChatGPT 3.5

Recently, GPT-4, a new version of ChatGPT was released for use by subscribers only. Developers claimed that the new version has been improved and can perform better compared to GPT-3.5 (OpenAI et al., 2023). To students, AI chatbots represent a valuable and easily accessible resource that can greatly aid in problem-solving, summarization, and delivering instant answers to inquiries, distinguishing them from other available tools. While recent reports, as previously mentioned, have shed light on the limitations and inaccuracies of ChatGPT in specific problem-solving scenarios, particularly in general chemistry, there re- mains a noticeable gap in available data regarding ChatGPT's performance in addressing organic chemistry questions, particularly those requiring an understanding of structural notations (Hallal et al., 2023). The integration of generative artificial intelligence (AI) in English language teaching presents opportunities and challenges for instructors. This study explores the attitudes of higher education English language instructors towards generative AI tools, their intentions to use them and the institutional support and professional development necessary to teach and learn with them (Kohnke et al., 2023). The use of ChatGPT in education has generated considerable interest due to its potential to enrich the learning experience of students. By providing quick and personalized responses, this system could address individual student needs, offer immediate feedback and facilitate the understanding of complex concepts. In this way, it becomes a promising tool that promotes a student's active participation and cognitive advancement by adapting to their learning pace and offering continuous support in their knowledge acquisition process (Montenegro-Rueda et al., 2023). Despite the advantages presented in it, it is essential to note that, in current times, the models have serious flaws that can significantly harm the students' learning process. Although tools like ChatGPT are, at first glance, abundant sources of information (Sarrazola-Alzate, 2023). This author tells us that artificial intelligence (AI) is a rapidly developing field. And it is based on GPT-3.5, the latest free version of ChatGPT available at the time of writing. In addition to dynamic changes in technology, the ethical implications of ChatGPT and other forms of AI are also advancing rapidly. Readers are advised to constantly check reliable sources for latest news and updates (Sethi et al., 2020). Teachers or students ask ChatGPT for ideas about how to extend students' learning after providing a summary of the current level of knowledge (e.g., quizzes, exercises). Understanding the role of study strategies and learning difficulties in students' academic performance to improve educational approaches: a proposal that uses artificial intelligence, and the most outstanding is ChatGPT 3.5 (Varela et al., 2024).

MATERIALS AND METHODS

How does ChatGPT and other forms of generative AI influence academic research and teaching-learning?

Generative artificial intelligence, such as ChatGPT, has a significant impact on academic research, teaching, and

business practices:

Academic Research:

Research Tasks: GenAI tools can be employed in various research tasks, but it is crucial to understand the best practices for their credible.

Biases: Researchers need to be aware of the biases inherent in GenAI tools and develop strategies to cope with them effectively.

Transparency*:* It is essential for researchers to be transparent about their use of GenAI tools in their manuscripts and clarify how these tools have been utilized.

Reliability and Validity*:* Continuous research is needed to assess the reliability and validity of using large language models (LLMs) in research tasks.

Teaching:

Integration into Education*:* Incorporating GenAI into education can enhance students' ability to solve real-world problems, such as in marketing, by training them to effectively use these tools.

Prompt Engineering: Teaching students how to craft effective prompts and evaluate GenAI output can improve their understanding and utilization of these technologies.

Ethical Use: Educators should guide students on using GenAI with integrity, transparency, and honesty, ensuring that assignments reflect original work rather than solely the output of GenAI. In summary, GenAI tools like ChatGPT have the potential to revolutionize academic research, teaching methods, and business practices by offering new opportunities for innovation, efficiency, and problem-solving. However, it is crucial for users to be aware of the limitations, biases, and ethical considerations associated with the use of these tools.

Why are certain Higher Education Professors not compatible with ChatGPT?

Higher education faculty are not incompatible with ChatGPT; In fact, this model can be useful in various areas of higher education. However, there are some aspects to consider:

Specific knowledge

ChatGPT has general and broad knowledge until its cut-off date in January 2022, but does not have access to real-time information or specific databases. Therefore, it may not be up to date on recent events or very specialized information.

Review and evaluation

The information provided by ChatGPT must be reviewed and evaluated by educational professionals to ensure its accuracy and relevance in specific contexts.

Adaptation to the educational context

The effectiveness of ChatGPT in higher education depends on how it is used and its integration with pedagogical methods. It can be a complementary tool for generating ideas, answering questions or as a source of information, but it cannot completely replace the experience and guidance of teachers.

Limitations on interaction

ChatGPT does not have the ability to understand context to the same extent as a human teacher. Although you can generate coherent responses, you do not have a deep or experiential understanding of the concepts.

Ethics and supervision

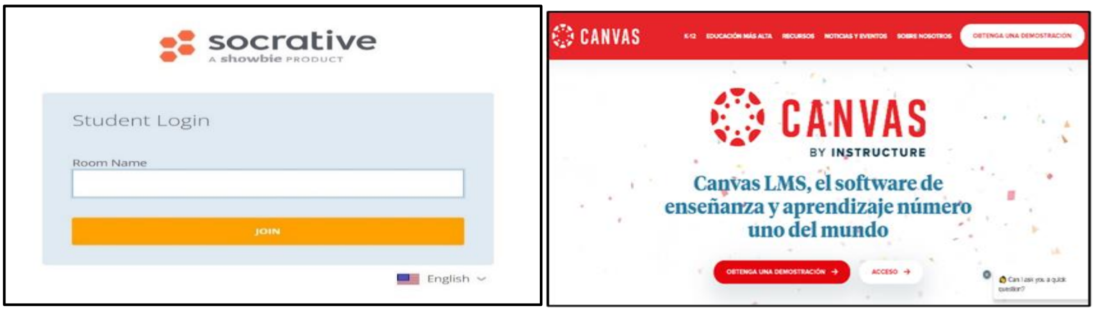
It is important to consider ethics in using technologies like ChatGPT in higher education. Furthermore, supervision and human intervention are essential to ensure a healthy and effective educational environment.

Despite these considerations, ChatGPT can be valuable in the classroom to provide instant information, support content generation, and stimulate reflection. However, it must be used in a conscious and balanced way, together with the experience and guidance of teachers, to make the most of its capabilities and overcome its limitations.

Tool applied at Higher Level

Technological tools applied in the teaching-learning process with higher education students at the Higher Technological Institute of San Andres Tuxtla, Veracruz, Mexico. (October-December 2023). The objective of this work was to investigate which technological tools are most used by students in a higher education institution and identify how this influence their educational process. The methodology was quantitative. 25 Industrial Engineering undergraduate students from the 7th semester participated. The data presented here is directly related to the use of the tools both at the school and individual level. Among the results obtained, the use of Microsoft Word as a word processor and Microsoft PowerPoint to make presentations stands out. Regarding the use of videoconferencing, very few teachers and students use this medium. The communication software that stands out the most is Meet. On the other hand, the device that students use most for their schoolwork is the computer, but in their daily lives they mainly use the smartphone. It was also possible to detect that students use more and more technological tools at school and in their common life and that these do not necessarily agree with those that the teacher recommends and reviews in class. They themselves take on the task of looking for applications that can be used for their school activities. This was demonstrated with the educational platforms they use, since they have not only used the institutional one, but others such as Canvas and Socrative stand out. In this research it was observed that, despite the fact that there are various applications for presentations, students continue to prefer Microsoft Office programs for their schoolwork. This information is relevant for teachers and can be useful to generate and apply various strategies in the classroom, since for students these tools are necessary in their educational process and can help improve their academic performance. How can study strategies integrated into artificial intelligence (AI) tools mitigate the impact of learning disabilities on academic performance? Achieving optimal academic performance is a multifaceted challenge that requires a profound understanding of study strategies and their interaction with learning disabilities (Varela et al., 2024).

Figure 1. Software of Socrative and Canvas mode students (Source: Software Platforms).



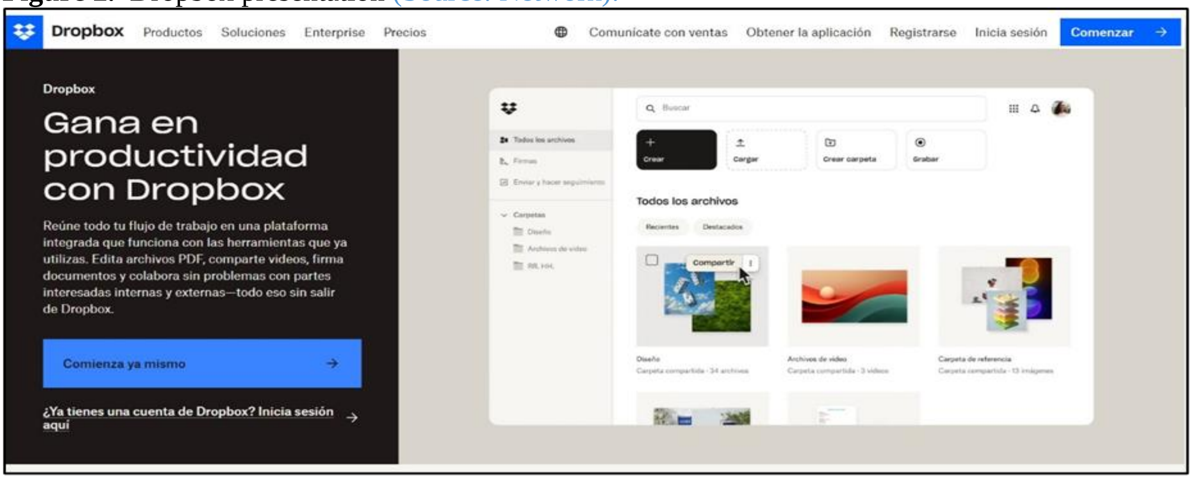
Nowadays, talking about technological tools is nothing new. The development of digital applications has adopted a frenetic pace. In the educational context, since the computer era appeared, it is quite common for students to use several of these tools when carrying out their academic tasks. Without a doubt, these resources have made their work easier: the time they use now is less than what they used previously. Before you had to physically go to the library, for example, now it is no longer necessary to travel, since consulting information material can be done from home through a laptop or desktop computer, mobile phone, tablet, in short, any device that is connected to the Internet. That is why we call this the fourth industrial revolution, or better known as Industry 4.0, thanks to Hyperconnectivity or IoT and the IIoT. Likewise, these tools have helped in the teaching-learning process, and not only for students, but also for teachers and parents. Now parents can become more involved in teaching their children, reaching limits that they could not have imagined some time ago. It is worth mentioning that sometimes students handle applications better than a teacher, especially if the teacher is older, since they were born in a time closer to the prevailing technological development. This helps both teachers and students to be able to learn in a more dynamic way, since the teacher also learns by teaching. The level of competitiveness will be higher as information and communication technologies (ICT) are used more for projects, tasks, and exercises in class. Due to the above, this work investigates the applications that a student uses at school, whether on the laptop, smartphone, or tablet. The objective is to know these tools to make them known and that this can help some teachers when choosing which ones to use in the classroom, and if they do not know them, begin to familiarize themselves with them for their classes. This is how ICT has helped make work easy and enjoyable. On the other hand, artificial intelligence refers to the ability of machines to imitate human intelligence and perform tasks that require human intelligence, such as pattern recognition, decision making, and autonomous learning (Vera, 2023).

Goals

1. Investigate which technological tools are most used by university students in a higher education institution.
2. Identify how these tools influence your educational process.
3. State the most outstanding tools so that teachers can generate and apply various strategies in the classroom and with them help improve student performance.
4. Specify the technological tools in which the teacher must continue updating.

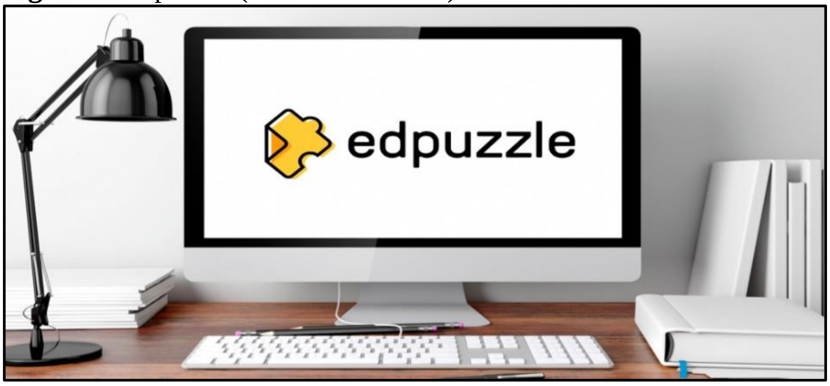
Digital resources supporting Higher Education

Figure 2. Dropbox presentation (Source: Network).



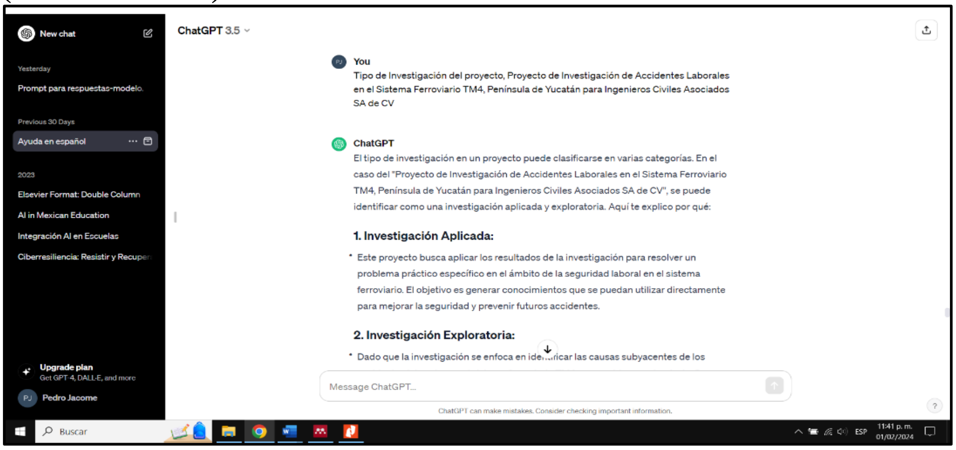
This software is for when you save a file to your Dropbox cloud storage, it is uploaded to our secure servers. Once the upload is complete, the file can be accessed from anywhere, using any computer, phone, tablet or other compatible device. The student who participated in this project already uses this mailbox. Dropbox is the space for all your work. You can store and share files, collaborate on projects, and bring your ideas to life. And all this alone or with colleagues and clients. With Dropbox, all your files are also in the cloud and available online.

Figure 3. Edpuzzle (Source: Network).



Edpuzzle; It is an online tool that allows us to edit and modify our own or online videos to adapt them to the needs of the classroom. Edpuzzle is an easy-to-use platform where you can turn any video into a lesson. With just one click, you can find video lessons created by other teachers, including formative assessment! With another click you can adapt that video by inserting your own questions or audio. This platform is also used by a group of young Industrial Engineering students from the Higher Technological Institute of San Andrés Tuxtla.

Figure 4. a) ChatGPT 3.5 personal presentation, **b)** Interface between human and artificial intelligence (Source: Network).



a)

b)

Because ChapGPT is a deep learning program, it is useful for extracting new information and improving its answers over time. This allows your communication strategies to be optimized and adapted to the needs of your company and your clients. The main functions that ChatGPT has are Answer questions about a particular topic. Write jokes and poems. Write detailed articles with a set number of words. ChatGPT is a free online tool, which is trained on millions of writing pages from all corners of the Internet to understand and answer text-based queries in almost any style you want.

Problematic

The excessive number of digital tools that exist today means that students can use some for school and others for personal use, in addition to causing teachers not to know which tools to use in class, whether for work, homework or Projects. The diverse use of these tools can cause the student's performance to be insufficient when submitting work, tasks, or projects. Various international reports identify education as a critical area to apply Artificial Intelligence (AI), with the potential to improve access and learning outcomes. With greater awareness of the applications and possibilities of AI in recent years, it has become the center of university debates, globally, from academic integrity to curricular adjustments and many other aspects of the learning experience. In this article we explore the main challenges and opportunities that higher education faces when integrating AI into the curriculum, with a focus on ChatGPT, from the perspective of a group of teachers (n=230). Responses are collected through a structured web-based interview. The results support the integration of AI in higher education.

RESULTS

The implementation of educational innovation in Mexico, specifically enhancing learning with artificial intelligence (AI) and the application of ChatGPT in higher education institutions with a perspective of teacher-student collaboration, has had several significant results. Here are some possible impacts:

Better Learning Experience:

The following table 1 shows a group of students from the Higher Technological Institute of San Andres Tuxtla, Veracruz, Mexico, (Higher Education), studying Industrial Engineering, who take this academic level study as a model to know what percentage of students are not familiar with one of the branches of artificial intelligence (AI), in the academic field, by asking about the use of ChatGPT 3.5. So here the table shows the percentage of knowledge of said learning tool. 75% have not used this tool through artificial intelligence (AI). and 25% if hiked.

Table 1. Percentage of ChatGPT knowledge in ES. (Own source).

No.	STUDENTS	AGE	EDUCATION	EXPERIENCE WITH ChatGPT	ACCEPTANCE BEFORE CHATGPT	ACCEPTANCE AFTER CHATGPT
1	201U0011	22	Engineering	YES	80%	100%
2	201U0012	23	Engineering	NO	40%	85%
3	201U0017	22	Engineering	YES	85%	100%
4	201U0020	21	Engineering	NO	40%	85%
5	201U0022	21	Engineering	NO	35%	90%
6	201U0023	23	Engineering	NO	39%	85%
7	231U0679	22	Engineering	NO	49%	95%
8	201U0030	21	Engineering	NO	40%	95%
9	201U0032	23	Engineering	NO	50%	100%
10	201U0033	23	Engineering	NO	48%	97%
11	201U0034	21	Engineering	NO	60%	100%
12	201U0035	23	Engineering	YES	85%	100%
13	201U0036	22	Engineering	NO	40%	90%
14	201U0037	22	Engineering	NO	20%	80%
15	201U0038	22	Engineering	YES	90%	100%
16	201U0039	22	Engineering	NO	40%	40%
		Percentages	25%			
		Percenteges	75%			

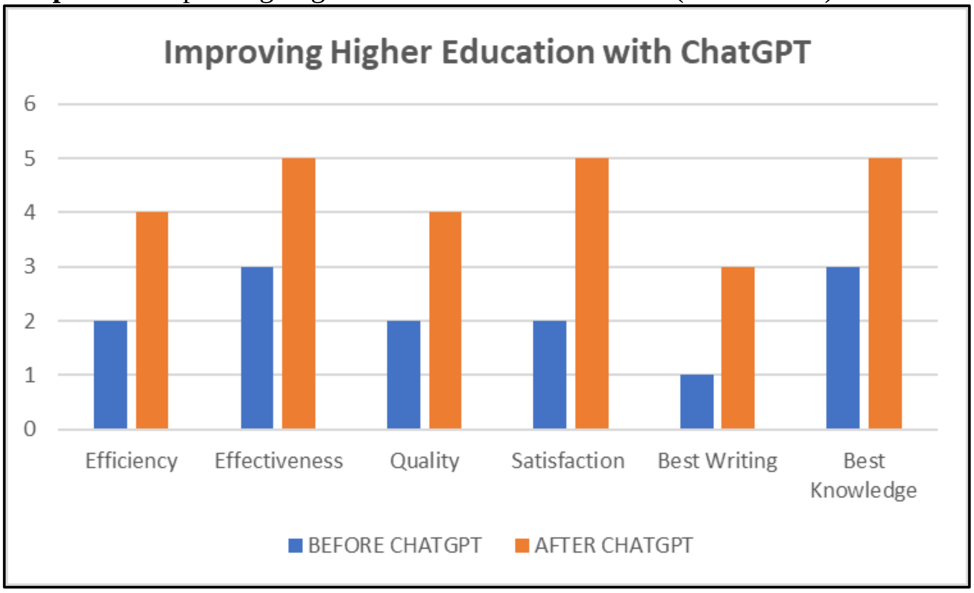
The impact of a change or improvement on a process is evaluated, and it is required to weight both the previous state (Before) and the subsequent state (After) in a table. A scale of 1 to 5 is used to assign values, with 1 indicating low impact and 5 indicating high impact. Evaluation criteria could be efficiency, effectiveness, quality, customer satisfaction, better writing and better knowledge.

Table 2. Criteria and increase in learning of ChatGPT 3.5 (Own source).

CRITERIOS	BEFORE CHATGPT	AFTER CHATGPT	INCREASE
Efficiency	2	4	2
Effectiveness	3	5	2
Quality	2	4	2
Satisfaction	2	5	3
Best Writing	1	3	2
Best Knowledge	3	5	2
Totals	**13**	**26**	**13**

In this example, each cell in the table has a value assigned for the state before the change (Before) of the CHATGPT knowledge and for the state after the change (After). Values are assigned by experts or based on quantitative data, depending on the availability of information and the nature of the criteria evaluated. Once you've assigned values to each cell, you can average the values for each state (Before and After) to get an overall measure of the impact of the change on each criterion. You can also perform a more detailed analysis considering the relative importance of each criterion by assigning specific weights to each of them. The following graphic 1. shows the behavior of the criteria that are evaluated to determine the increase in the use of Artificial Intelligence (AI) through ChatGPT in higher education students in Mexico. As mentioned in the name of the article with the collaboration between Teachers-students.

Graphic. 1. Improving Higher Education with ChatGPT (Own source).



Communication facilitation has been achieved

The use of ChatGPT has improved teacher-student communication, allowing instant responses to queries and facilitating online interaction, especially in virtual learning environments. clarifying that in these activities there must be values such as honesty and ethics, so that positive results are achieved.

DISCUSSION

This framework provides a solid foundation for a technical and thoughtful discussion about how artificial intelligence, specifically ChatGPT, can improve learning in higher education institutions and promote more effective collaboration between faculty and students. A technology discussion on enhancing learning with artificial intelligence (AI), specifically the application of ChatGPT in higher education institutions and its impact on teacher-student collaboration, could address several key aspects. Here is an outline of how that discussion might be structured.

Advantages of the ChatGPT application in learning

Instant information access: Students can get answers to their questions immediately, encouraging exploration and self-directed learning. **Personalization of learning:** ChatGPT can adapt to the individual needs of students, providing resources and explanations tailored to their level of understanding and learning style. **Supporting the teaching process:** Teachers can use ChatGPT as a complementary tool to provide quick feedback and additional resources to students. **Encouragement of creativity and reflection:** Interacting with ChatGPT can inspire students to explore new ideas and perspectives, as well as reflect on their own learning process.

Teacher-student collaboration

Real-time support: ChatGPT can facilitate communication between teachers and students outside of class hours, giving students access to additional guidance and resources when they need it most. **Encouraging dialogue:** Interaction with ChatGPT can serve as a starting point for deeper classroom discussions, stimulating critical thinking and debate. **Student Empowerment:** By providing students with tools to search and understand information independently, ChatGPT can foster a sense of autonomy and responsibility in the learning process.

With these own comments in the discussion, versions of other authors are demonstrated in the opinion about the empowerment of ChatGPT in higher education in Mexico. To conclude, ChatGPT can provide assistance in many new research areas, and we are still at the very early stage of exploring its application scope. I have no doubt that AI tools will become a game-changing player in all fields, including our scientific society. However, there are many challenges in terms of research purposes. So far ChatGPT is limited by computational constraints, the ability to point out inaccurate information or false faces, and inferential capability for scientific research. All those limitations may lead to misunderstandings or misinterpretation. To address these challenges, researchers are immersing themselves to improve the accuracy and reliability of the model (Cheng, 2023).

CONCLUSION

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Recap of the benefits and challenges of applying ChatGPT in higher education institutions. as well as encouraging an ethical and thoughtful implementation of AI in the educational environment, with a focus on improving the learning experience and promoting collaboration between teachers and students. This framework provides a solid foundation for a technical and thoughtful discussion about how artificial intelligence, specifically ChatGPT, can improve learning in higher education institutions and promote more effective collaboration between faculty and students.

This article illuminates the impressive potential of using ChatGPT in this context, since 75% of respondents from a population of higher-level students have not been familiar with this technological tool and 25% require more updating, but are familiar. . This highlights the potential of ChatGPT as a powerful tool for educators, enabling the creation of personalized educational content that can resonate with students from a wide range of academic backgrounds.

BIBLIOGRAFHIC REFERENCES

Cheng, H. (2023). *Challenges and Limitations of ChatGPT and Artificial Intelligence for Scientific Research : A Perspective from Organic Materials*. 401–405.

Chiu, T. K. F. (2024). Computers and Education : Artificial Intelligence Future research recommendations for transforming higher education with generative AI. *Computers and Education: Artificial Intelligence*, *6*(December 2023), 100197. https://doi.org/10.1016/j.caeai.2023.100197

Einarsson, H., Lund, S. H., & Jónsdóttir, A. H. (2024). Computers and Education : Artificial Intelligence Application of ChatGPT for automated problem reframing across academic domains. *Computers and Education: Artificial Intelligence*, *6*(December 2023), 100194. https://doi.org/10.1016/j.caeai.2023.100194

Habibi, A., Muhaimin, M., Kopong, B., Gusti, Y., Wahyuni, S., & Octavia, A. (2023). Computers and Education : Artificial Intelligence ChatGPT in higher education learning : Acceptance and use. *Computers and Education: Artificial Intelligence*, *5*(December), 100190. https://doi.org/10.1016/j.caeai.2023.100190

Hallal, K., Hamdan, R., & Tlais, S. (2023). Computers and Education : Artificial Intelligence Exploring the potential of AI-Chatbots in organic chemistry : An assessment of ChatGPT and Bard. *Computers and Education: Artificial Intelligence*, *5*(October), 100170. https://doi.org/10.1016/j.caeai.2023.100170

Kohnke, L., Luke, B., & Zou, D. (2023). Computers and Education : Artificial Intelligence Exploring generative artificial intelligence preparedness among university language instructors : A case study. *Computers and Education: Artificial Intelligence*, *5*(June), 100156. https://doi.org/10.1016/j.caeai.2023.100156

Lund, B. D., & Wang, T. (2023). Chatting about ChatGPT: how may AI and GPT impact academia and libraries? *Library Hi Tech News*, *40*(3), 26–29. https://doi.org/10.1108/LHTN-01-2023-0009

Montenegro-Rueda, M., Fernández-Cerero, J., Fernández-Batanero, J. M., & López-Meneses, E. (2023). Impact of the Implementation of ChatGPT in Education: A Systematic Review. *Computers*, *12*(8), 1–13. https://doi.org/10.3390/computers12080153

OpenAI, :, Achiam, J., Adler, S., Agarwal, S., Ahmad, L., Akkaya, I., Aleman, F. L., Almeida, D., Altenschmidt, J., Altman, S., Anadkat, S., Avila, R., Babuschkin, I., Balaji, S., Balcom, V., Baltescu, P., Bao, H., Bavarian, M., … Zoph, B. (2023). *GPT-4 Technical Report*. *4*, 1–100. http://arxiv.org/abs/2303.08774

Peres, R., Schreier, M., Schweidel, D., & Sorescu, A. (2023). Editorial: On ChatGPT and beyond: How generative artificial intelligence may affect research, teaching, and practice. *International Journal of Research in Marketing*, *40*(2), 269–275. https://doi.org/10.1016/j.ijresmar.2023.03.001

Sarrazola-Alzate, A. (2023). Uso de ChatGPT como herramienta en las aulas de clase. In *Revista Eia* (Vol. 20, Issue 40, pp. 1–23). https://doi.org/10.24050/reia.

Sethi, K., Chauhan, S., & Jaiswal, V. (2020). *Artificial Intelligence in Higher Education*. 1–29. https://doi.org/10.4018/978-1-7998-4763-2.ch001

Steele, J. L. (2023). Computers and Education : Artificial Intelligence To GPT or not GPT ? Empowering our students to learn with AI. *Computers and Education: Artificial Intelligence*, *5*(May), 100160. https://doi.org/10.1016/j.caeai.2023.100160

Varela, C., Bressane, A., Zwirn, D., Essiptchouk, A., Luiz, F., Carvalho, D. C., Kennety, J., Formiga, S., & Líliam, C. (2024). *Computers and Education : Artificial Intelligence Understanding the role of study strategies and learning disabilities on student academic performance to enhance educational approaches : A proposal using artificial intelligence*. *6*(December 2023). https://doi.org/10.1016/j.caeai.2023.100196

Vera, F. (2023). Integración de la Inteligencia Artificial en la Educación superior: Desafíos y oportunidades. *Revista Electrónica Transformar Transformar Electronic*, *4*(1), 1–18. https://orcid.org/0000-0002-4326-1660

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COMPUTATIONAL PERFORMANCE OF HOLE FILLING MORPHOLOGICAL ALGORITHMS FOR BINARY IMAGES

Gonzalo Urcid [1], José-Angel Nieves-Vázquez [2], Rocío Morales-Salgado [3]

[1] Ph.D., Optics Department, INAOE, Tonantzintla 72840, Mexico
[2] Ph.D., Engineering Division, ITSSAT, Matacapan 95804, Mexico
[3] Ph.D., Information and Data Science Department, UPAEP, Puebla 72410, Mexico

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Corresponding Author

Gonzalo Urcid, gurcid@inaoep.mx

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ABSTRACT

The presence of holes, cracks or scratches in one or more object regions in a binary image usually results from quantizing or thresholding a gray scale image. However, for further processing or quantitative binary image analysis, those artifacts must be removed by filling the corresponding object regions. In this paper, a computational performance analysis is realized for the class of hole filling algorithms based on mathematical morphology. Two fundamental techniques, supervised and unsupervised, are described in detail based on marker images that may be composed of pixel subsets chosen within an object region artifact, formed by external near by points to object regions, or from selected background pixel subsets. A mathematical description spanning the different variants is given on how this kind of algorithms converge to the desired result. In addition, illustrative examples using representative binary images are provided to test and compare the computational performance in terms of the number of iterations corresponding to each morphological hole filling algorithm for binary images.

Keywords: Binary Image Processing, Hole Filling Algorithms Performance, Mathematical Morphology

1. INTRODUCTION

The subject of morphological binary image processing Serra (1986), Maragos (1987), Haralick et al. (1987), Dougherty (1992) is a branch of the more general subject of digital image processing and analysis. Binary image processing deals with black and white digital images whose values are coded with 0's and 1's, where the zero '0' and one '1' values are commonly interpreted, respectively, as background and foreground pixels. The foreground pixels may form one or more white shapes or regions in the image that usually correspond to objects of interest surrounded by a black background Pitas (2000), Gonzalez & Woods (2018). Since binary images are a special case of gray scale images, it turns out that for "looking" or "displaying" a binary image coded with 0's and 1's, it is mapped to the gray scale dynamic range of non-negative integer values belonging to [0,255] assuming that the grayscale image is coded with 8 bits per pixel. Hence, for displaying purposes, the minimum value '0' still represents black and the maximum value '255' corresponds to white. Image processing tasks such as object segmentation and object recognition may produce a binary image that is obtained from thresholding or quantizing a grayscale image Pitas (2000), Najman & Talbot (2010), Gonzalez & Woods (2018), Gonzalez et al. (2020). The output binary image then requires some kind of post-processing to prepare it for further analysis. A typical situation is the presence of holes, cracks, or scratches in several regions of a binary image that need to be removed by filling them. For example, possible reasons for the presence of holes in a binary image is due to occluding objects, low reflectance subregions, or missing scanned portions ocurring in grayscale images. We remark that using the corresponding digital topology associated with an underlying digital grid such as the square grid, holes, cracks, and scratches can be considered as the same type of image artifact. Henceforth, we will use the word "hole" to represent any of the previously mentioned items. From a geometrical point of view, based on set theory, mathematical morphology has devised simple and effective hole filling algorithms to tackle the aforementioned problem as can be seen in Vincent (1992), Vincent (1993), Géraud et al. (2010) . In this research paper, we present a computational performance analysis of the fundamental region filling procedures based on mathematical set morphology.

Recent contributions with respect to the basic hole filling morphological algorithms are described in Hasan & Mishra (2012), Valdiviezo et al. (2017). The work presented in Hasan & Mishra (2012) suggests the use of a different initial marker image for increasing the number of seed points used in the dilation operation as well as the dynamic use of two structuring elements, the "diamond" and "square" structuring elements of size 3×3, combined with thresholding for corrections of local 4-connectivity and 1-pixel-thin border object processing. On the other hand in Valdiviezo et al. (2017), a supervised hole filling algorithm based on morphological conditional dilation is based on chosing a single background pixel as the marker image and has the advantage of being very simple. However, this last scheme although interactive in nature, happens to be a particular case of the more general mechanism explained in Subsection 3.2 for the unsupervised algorithm. Also, alternative advances that realize improvements over the hole filling morphological algorithms are described in Fanfeng & Wei (2010), He et al. (2019). However, we do not delve into these last works since their computer implementation requires additional *non-morphological* techniques that would require other performance measures besides the number of iterations that we have selected for our computational tests.

Our paper is organized as follows: in Section 2 we will give only the necessary mathematical morphology operations involved in hole filling algorithms. However, for the interested reader, in depth treatments of the basic morphological operations including additional ones derived using dilation and erosion, their algorithmic implementation as well as their applications to other tasks in digital image processing and analysis can be found in Rivest et al. (1993), Van Droogenbroeck (1994), Bloch et al. (2007), Beucher & Beucher (2012), Gonzalez & Woods (2018) and Gonzalez et al. (2020). Section 3 gives in detail the theoretical description of the fundamental mathematical morphology hole filling techniques emphasizing the central role of the marker image and henceforth, classifying the corresponding computational procedures as supervised or unsupervised. In Section 4, we present our tests on various representative binary digital images using as a measure of computational performance, the number of iterations needed in each algorithm as applied to each binary image to produce the desired result. We end our paper with Section 5 to expose the conclusions of this research work as well as some pertinent comments on future developments.

2. BACKGROUND ON MATHEMATICAL MORPHOLOGY

Mathematical morphology as applied to digital image processing is a mathematical theory that is concerned with analysing and extracting *form* or *shape* information from objects contained in a given image. The basic scenario does occur in binary images where the notions of foreground objects and background are in general clearly distinguished in the context of specific real-world applications. Two encodings are possible in binary image processing, i. e., *white foreground* (WF) objects immersed in a *black background* (BB), denoted for short as WF-BB, or *black foreground* (BF) objects embedded in a *white background* (WB) abbreviated as BF-WB. Algebraically speaking, both encodings, WF-BB and BF-WB, are dual to each other using binary complementation. Here we will use the first encoding. Note that the WF-BB coding is a particular case of grayscale 8-bit encoding whose dynamic range of 256 values is reduced from the non-negative integer interval, $[0,255] \subseteq \mathbb{N}$, to the two-value set $\{0,255\}$. On the other hand, the BF-WB encoding is generally employed in silhouette, artistic binary image processing or in theoretical descriptions based on graph theory. In this paper, only square images of size $n \times n$ picture elements are used to simplify symbolic expressions in mathematical arguments and also since the extension to rectangular images is rather trivial.

2.1. OPERATIONS ON SETS, DILATION AND EROSION

We assume the reader is familiar with set relations such as inclusion and equality as well as the set operations of union, intersection, difference, and complementation. Some geometrical operations on sets follow. If $S = \mathbb{Z}^2$, with origin $O = (0,0)$, represents the two-dimensional digital space, let $A \subseteq S$, then the *complement* A is defined as $A^c = \{x \in S | x \notin A\}$, and the *symmetrical*, *origin reflected* or *transpose* of A is considered to be the set $\check{A} = \{-x \in S | x \in A\}$. Also, if $x \in S$, the *translation* of A by x, or *translate* A_x is the subset of S specified by $A_x = \{\xi + x | \xi \in A\}$. In order to extract shape information from objects contained in a given image, the basic mechanism from the stand point of mathematical morphology, is to use a geometrically well-defined tiny shape as a probe that scans and interacts pixelwise with foreground objects and background. The elementary morphological operations, known as *dilation* and *erosion*, work with these tiny shapes formally called *structuring elements*, respectively to grow or shrink image objects. Thus, given a binary image A and a structuring element B, both considered as subsets of S, *dilation* and *erosion* of image set A by structuring element B are defined, respectively, by the left and right expressions in (1),

$$A \oplus B = \left\{x \in S \middle| (\check{B})_x \cap A \neq \emptyset\right\} = \bigcup_{b \in B} A_b \quad ; \quad A \ominus B = \{x \in S | B_x \subseteq A\} = \bigcap_{b \in B} A_{-b}, \qquad (1)$$

where x denotes locations or points in digital space S and $(\check{B})_x$ and B_x denotes the translate of the symmetric structuring element, respectively, itself, to location $x \in S$. Note that dilation of A by B, denoted as $A \oplus B$, is a new set formed by all points

$x \in S$ such that $\check{B}$ displaced at each x, overlaps or hits at least some portion of A. Analogously, erosion of A by B, in symbolic terms $A \ominus B$, refers to a new set consisting of all points $x \in S$ such that B translated by x fits completely within A. The second equality shown in the left and right expressions in (1) are the equivalent set-theoretical operations corresponding to Minkowski addition and Hadwiger substraction, which make clear, the upsizing or downsizing nature of A by B through a generalized union or intersection of translates. We point out that dilation and erosion are *dual by complementation* in the sense that dilating set A with structuring element B is equivalent to perform and erosion of its complement A^c with the symmetrical of $\check{B}$ as established in (2),

$$(A \oplus B)^c = A^c \ominus \check{B} \quad ; \quad (A \ominus B)^c = A^c \oplus \check{B}. \tag{2}$$

Qualitatively, dilation enlarges an object, changes its convex corners, and reduces its surrounding background. Similarly, erosion reduces an object, changes its concave corners, and enlarges its neighbouring background. In relation to the morphological region filling algorithms exposed in Section 3, we will use only the dilation operation together with set complementation. Particularly, if B is a structuring element the *repeated dilation* of B with itself, i. e., $B \oplus B$ is written as $2B$. In addition, if A is a single element set, i. e., $A = \{x\}$, then from (1) it follows readily that,

$$\{x\} \oplus B = B_x \quad ; \quad \{x\} \ominus B = \emptyset, \tag{3}$$

meaning that dilation of a single (isolated) point x by B is equivalent to a geometrical translation of B to x which is coincident with B's origin. Also, erosion of a single point x by B has the effect of removing the point since B displaced to x is not a subset of $\{x\}$. A structuring element will be abbreviated as SE. More specifically, use is made of 3×3 SE's having 4-connectivity (*straight cross* '+' or *diagonal cross* '×'), and 8-connectivity (*square block* '■').

2.2. IMAGE BORDER, HOLES AND LOCAL KNOWLEDGE

For a binary image $A = (a_{ij})$ of size $n \times n$ pixels, the *border* or *frame* of A, denoted by ∂A, is defined by the set of pixels given by the union of the *top* (first) and *bottom* (last) *rows* of pixels together with the *left* (first) and *right* (last) *columns* of pixels. Thus, $\partial A = R_t \cup R_b \cup C_l \cup C_r$, where $R_t = \{a_{0j} | j = 0, \cdots, n-1\}$, $R_b = \{a_{n-1j} | j = 0, \cdots, n-1\}$, $C_l = \{a_{i0} | i = 0, \cdots, n-1\}$, $C_r = \{a_{in-1} | j = 0, \cdots, n-1\}$, and $a_{ij} \in \{0,255\}$ for all *i* and *j*. A *hole* is defined as a background region in which any pixel is surrounded by a connected path of foreground pixels. An alternative definition of a hole is a background region that is bounded by a foreground object. Equivalently, no connected path of background pixels exists between any pixel in a hole and a background pixel of ∂A. It should be clear that the border of an image not only delimits its size but also its contents. Hence, a physical sensor of finite dimensions that acquires or captures an image from a *real scene* will provide us with *partial* or *local knowledge* relative to objects or foreground regions contained in the original scene. In the case of objects with holes, ∂A may cut or truncate portions of their corresponding regions leaving them "unfinished" or "incomplete" beyond the image frame. Therefore, in a strict sense, truncated holes, cracks or scratches cannot be considered as such due to incomplete knowledge outside the image border.

However, the ocurrences just mentioned may be filled or not depending of contextual image content and its interpretation for further processing.

3. MORPHOLOGICAL REGION FILLING ALGORITHMS

The hole filling algorithms based on mathematical morphology can be categorized as *supervised* or *unsupervised*, and each one of them is founded on specific morphological set operations between the image itself and an auxiliary image known as the *marker image*, which in turn is derived from the given input image. The algorithms have been devised to be iterative in nature and therefore convergence to the desired result, i. e., the filled image is guaranteed to be obtained in a finite number of steps.

3.1. SUPERVISED FILLING ALGORITHM

A mathematical morphology hole filling algorithm is said to be *supervised* if the marker image is derived from the input image by selecting interactively an adequate subset of pixels. The chosen pixels may belong to image oject regions, to the image background or a mixture of both. Assuming that m holes H_i for $i = 1, \cdots, m$ exist in one or more objects as foreground regions in a given binary image A of size $n \times n$, the common choice, as exposed in preliminary treatments on mathematical morphology of sets and its applications to binary images Gonzalez & Woods (2018), Gonzalez et al. (2020) consists in taking a single point or pixel p_i^α belonging to each hole H_i. Thus, the *marker image* M or *set of markers* is defined as the set $M = \{p_i^\alpha \in H_i | i = 1, \cdots, m\}$, where $M = M_0$ is not a proper subset of A and $m \ll n^2$. The basic morphological hole filling algorithm consists of an iterative scheme based on *conditional dilation* as specified in the following equation:

$$M_l = (M_{l-1} \oplus B) \cap A^c \,;\;\; l = 1, \cdots, k \tag{4}$$

where, $B = \check{B}$ is a symmetric structuring element corresponding to 3×3 *elementary neighborhood* with 4 (straight or diagonal cross), 6 (hexagon) or 8 (square) connectivity, and A^c is the complement of A. Computation of M_l is repeated until $M_{k+1} = M_k$ and the final iteration stops at $l = k$. In the last step, the union set $M_k \cup A$ contains the original object regions with their holes, cracks, or scratches filled. Note that, in (4), the intersection of $M_{l-1} \oplus B$ at each iteration with A^c limits the expanding effect of performing successive dilations. To cover every aspect, we explain in more detail how the basic algorithm works. Specifically, we can write the marker set as $M_0 = \bigcup_{i=1}^m \{p_i^\alpha\}$, where each point $p_i^\alpha \in H_i$ and H_i is a subset corresponding to a hole within an object region that properly may have more than one hole and which we write as $\mathcal{R}^H$. We also assume that the structuring element contains the origin, thus $0 \in B$. Unfolding the iterative conditional dilation for $l = 1$ we have that

$$M_1 = (M_0 \oplus B) \cap A^c = \left(\left[\bigcup_{i=1}^m \{p_i^\alpha\}\right] \oplus B\right) \cap A^c = \left(\bigcup_{i=1}^m [\{p_i^\alpha\} \oplus B]\right) \cap A^c$$
$$= \left(\bigcup_{i=1}^m B_{p_i^\alpha}\right) \cap A^c = \bigcup_{i=1}^m B_{p_i^\alpha}$$

where $B_{p_i^\alpha}$ is the structuring element translated to point p_i^α after applying the first expression in (3), and $B_{p_i^\alpha} \subset A^c$ for any i. Similarly, for $l = 2$, we obtain,

$$M_2 = (M_1 \oplus B) \cap A^c = \left(\left[\bigcup_{i=1}^{m} B_{p_i^\alpha}\right] \oplus B\right) \cap A^c = \left(\bigcup_{i=1}^{m} \left[B_{p_i^\alpha} \oplus B\right]\right) \cap A^c$$
$$= \left(\bigcup_{i=1}^{m} 2B_{p_i^\alpha}\right) \cap A^c = \bigcup_{i=1}^{m} 2B_{p_i^\alpha}.$$

Note that, $B_{p_i} \oplus B$ can be written as $2B_{p_i}$ since dilation at each iteration is performed on the previously grown set B_{p_i}. Thus, the result of the l-th iteration is given by $M_l = \bigcup_{i=1}^{m} lB_{p_i^\alpha}$, where $lB_{p_i^\alpha} = (l-1)B_{p_i^\alpha} \oplus B$. At this stage, several points in M_0 have been expanded to their corresponding hole sizes and the remaining unfilled holes still require further iterations until the growing scheme stops after masking once more with A^c. Therefore, for $k > l$, it happens that $(k+1)B_{p_i^\alpha} = kB_{p_i^\alpha}$ which in turn implies that $M_{k+1} = M_k$, and the resulting set, $M_k = \bigcup_{i=1}^{m} kB_{p_i^\alpha}$ contains the required flooded holes. Finally, set $A_f = A \cup M_k$ gives the desired result by gluing all the filled holes with the original image. Consequently, all multiconnected foreground regions or equivalently objects with one or more holes are changed to simple connected regions, i. e., objects without holes, cracks or scratches. The supervised morphological filling algorithm will be abbreviated as SMFA.

3.2. UNSUPERVISED FILLING ALGORITHM

A mathematical morphology hole filling algorithm is said to be *unsupervised* if the marker image is derived from the input image by means of a mathematical function or by an automatic procedure that defines an adequate proper subset of pixels (cf., e.g., Hasan & Mishra (2012) and Gonzalez & Woods (2018)). Again, selected image points may be background, foreground or a combination of both types of pixels. In the present context used is made of what is known as *morphological reconstruction* and the terminology is changed to convey its generality upon application of more advanced morphological mathematical operations such as opening or closing which fall outside the scope of this work. Specifically, morphological conditional dilation turns to be *morphological geodesical dilation*, the input or source image is consider as a *mask* to control geodesical dilation growth or reconstruction, and the role of the marker image is the same as previously explained, except that it is defined by a mathematical function as already mentioned above. For the case at hand, the marker image M corresponding to the mask image usually denoted by G is given by,

$$M = (G - G) \cup (255 - \partial G). \tag{5}$$

Interpretation of (5) in terms of image content is that, $G - G = \emptyset$, a set difference equal to the void set gives us a full black background image of which we change the image border, i.e., $255 - \partial G$ with white pixels all around except where foreground objects touch it and become black pixels. If (i, j) denote the integer spatial coordinates of image G (the mask or input image), where $i, j = 0, \cdots, n-1$, then the matrix expression associated with (5) is the following:

$$M_{ij} = \begin{cases} 255 - G_{ij}, & G_{ij} \in \partial G, \\ 0, & G_{ij} \notin \partial G. \end{cases} \tag{6}$$

Worth to remark is the fact that the marker image M as established in (6) is a set of pixels with a special structure that is not a subset of G. In particular, if G_{ij} is a background pixel then $M_{ij} = 255$, meaning that the selected image border pixel is turned "on", i. e., becomes a marker. In case G_{ij} is a foreground pixel then $M_{ij} = 0$, hence the corresponding image border pixel is turned "off" or equivalently is not consider a marker point. Thus, M contains *only background* pixels as marker points. As mentioned earlier, in morphological processing several image manipulations are derived from a parametric operation known as *morphological recontruction* that considers two images, the marker image M and the mask image G together with a symmetric structuring element B which is a 3×3 elementary neighborhood with 4, 6 or 8 connectivity. Notice that in general G is not necessarily equal to a given input image A. Furthermore, in the case of filling one or more holes using (6) it turns out that $G = A^c$. Particularly, the *morphological geodesic dilation of size n* is defined recursively as,

$$\delta_G^n(M) = \delta_G^1[\delta_G^{n-1}(M)] \text{ where } \delta_G^1(M) = (M \oplus B) \cap G, \tag{7}$$

expression interpreted as the morphological geodesic dilation of size 1. Recalling the way M is defined, the unsupervised hole filling algorithm using morphological geodesic dilation is based on the following iterative procedure,

$$\delta_G^l(M) = \delta_G^1\left[\delta_G^{l-1}(M)\right] \text{ for } l = 1, \cdots k, \tag{8}$$

until stability is accomplished, i. e., when $\delta_G^{k+1}(M) = \delta_G^k(M)$ and $l = k$ is the last iteration. In the final step, the output or final image A_f with all holes filled is determined by computing,

$$A_f = \left[\delta_G^k(M)\right]^c. \tag{9}$$

Again, for the sake of completeness, we present how the algorithm given by (8) and (9) works. As before, we can write the marker set as $M = \bigcup_{i=1}^m \{p_i^\beta\}$, where each point $p_i^\beta \in \partial A$, $m \leq 4n$, and ∂A is the subset corresponding to the image border. Note that M does not contain any point marking a hole within an object region. Recalling that the structuring element contains the origin, i. e., $0 \in B$ and that the mask $G = A^c$, the morphological geodesic dilation for $l = 1$ is given by

$$\delta_G^1(M) = (M \oplus B) \cap G = \left(\left[\bigcup_{i=1}^m \left\{p_i^\beta\right\}\right] \oplus B\right) \cap G = \left(\bigcup_{i=1}^m \left[\left\{p_i^\beta\right\} \oplus B\right]\right) \cap G$$

$$= \left(\bigcup_{i=1}^{m} B_{p_i^\beta} \right) \cap G = \bigcup_{i=1}^{m} B_{p_i^\beta}$$

where $B_{p_i^\beta}$ is the structuring element translated to point p_i^β after applying the first expression in (3), and $B_{p_i^\beta} \subset G$ for any i. Similarly, the morphological geodesic dilation for $l = 2$, results in,

$$\delta_G^2(M) = \delta_G^1[\delta_G^1(M)] = (\delta_G^1(M) \oplus B) \cap G = \left(\left[\bigcup_{i=1}^{m} B_{p_i^\beta} \right] \oplus B \right) \cap G$$
$$= \left(\bigcup_{i=1}^{m} \left[B_{p_i^\beta} \oplus B \right] \right) \cap G$$
$$= \left(\bigcup_{i=1}^{m} 2B_{p_i^\beta} \right) \cap G = \bigcup_{i=1}^{m} 2B_{p_i^\beta}$$

In similar fashion, the result of the l-th iteration is given by $\delta_G^l(M) = \bigcup_{i=1}^{m} lB_{p_i^\beta}$, where $lB_{p_i^\beta} = (l-1)B_{p_i^\beta} \oplus B$. At this stage, all points in M have been expanded within the mask G covering almost all space outside the exterior edges of object regions with or without holes, no matter their number or size. Further iterations fills up the remaining external space and dilation stops after masking once more with G and obtaining a result equal to the previous one. Therefore, for $k > l$, it happens that $(k+1)B_{p_i^\beta} = kB_{p_i^\beta}$ which in turn implies that $\delta_G^{k+1}(M) = \delta_G^k(M)$, and the resulting set, $\delta_G^k(M) = \bigcup_{i=1}^{m} kB_{p_i^k}$ contains the flooded space that surrounds the exterior edges of all object regions. Finally, set $A_f = \left[\delta_G^k(M)\right]^c$ gives the desired result since the complement of the external space between all object regions contains all original foreground regions including those with filled holes. In this case, the set difference, $A_f - A$ gives an image with all filled holes, cracks, or scratches. The unsupervised morphological filling algorithm will be abbreviated as UMFA.

3.3. ALGORITHM COMPARISON

From the discussion presented in Subsections 3.1 and 3.2, it can be seen that the supervised and unsupervised versions of the morphological hole filling algorithm share the same structural iterative procedure to attain their goal. However, as has been explained in detail, their main difference resides in the way the marker image is established, which in turn distinguishes their mode of operation, that is, interactive versus automatic, hence the use of a superscript for marker points within holes versus the use of the β superscript for marker points belonging to the image border.

In supervised mode we made the assumption that the number of holes is much less than the number of pixels in a given square image, i. e. $m \ll n^2$, which in turn is related to the number of connected or multiconnected object regions. In unsupervised mode, the number of seed points or initial markers is bounded by the number of pixels on the image border, i. e. $m \leq 4n$, and is derived from the manner in which the marker image is defined by means of a mathematical function. It is not difficult to see that the variables n and m are essential to determine the computational complexity of each algorithm. However, to date there is no explicit functional expression for the corresponding computational complexity for parallel and sequential implementations of both algorithms (cf. Sec. IV in Vincent (1993)). Nonetheless, computational tests can be based on measuring execution time or counting the number of iterations to achieve the desired result. Execution time is dependent on computing machinery characteristics and iteration count depends on programming implementation either parallel or sequential. Specifically, we will use the iteration count criterion to compare our implementation of the morphological filling algorithms previously described.

4. COMPUTATIONAL TESTS ON BINARY IMAGES

The results obtained with a computer implementation of the supervised and unsupervised morphological hole filling algorithms using the Mathcad high level programming language are presented in detail. In comparing both techniques, 15 binary images of size 256×256 pixels with WF-BB encoding were used. However, to ilustrate visually the results obtained, 8 digital binary images were selected as displayed in Figure 1. A description of all test images is listed in Table 1 where selected images for display are marked on the right with an asterisk (*).

Table 1

Table 1 Set of 16 Test Binary Images used for Morphological Hole Filling

Test Image	Holes	Description
‘00’	2	two-hole small image 32×32 px (initial testing)
‘01’	1	single hole within a disk
‘02’	14	multiple round holes
‘03’	15	multiple irregular holes
‘04’	6	multiple holes of different shapes *
‘05’	3	holes and scracthes *
‘06’	10	set of simple tools, several shapes *
‘07’	34	several simple object silhouettes *
‘08’	13	multiple holes within particles
‘09’	23	multiple holes within irregular particles *
‘10’	43	multiple small holes within cells
‘11’	29	multiple sector holes in a circular pattern *
‘12’	30	holes in letters of a sample text
‘13’	20	holes in letters of unequal size & orientation *
‘14’	57	multiple sized holes within a natural scene *
‘15’	6	holes within an artificial object composition

In the following pages, the results obtained with the supervised morphological filling algorithm (SMFA) are shown in Figure 2, Figure 3, Figure 4, Figure 5. Next, the results obtained with the unsupervised morphological filling algorithm (UMFA) are given in Figure 6, Figure 7, Figure 8, Figure 9. In both groups of results the structuring element used was the straight cross ‘+’ of size 3×3 pixels whose corners are turned ‘off’ (0) and any other pixel is ‘on’ (255). For visualization purposes points within holes, serving as markers, are displayed as white boxes of size 3×3 pxs and clearly, only the center point is employed for operating with the SMFA. Similarly, background points on the image border ∂A used as markers have been dilated to a 3×3 pixel size and shown in red color to emphasize their nature. Again, only single pixels belonging to the image border are used to operate the UMFA. The numerical values of the iteration count for each test binary image using both algorithms with SE's, '+' (4-connectivity) and '■' (8-connectivity) are listed in Table 2 that appears after Figure 9.

Figure 1

Figure 1 1st Group of 8 Sample Binary Images Selected from a set of 15 Test Images. Label Numbers from Left to Right, Top to Bottom is '04', '05', '06', '07', '09', '11', '13', '14' and Separation Between Images is Shown in Gray.

Figure 2

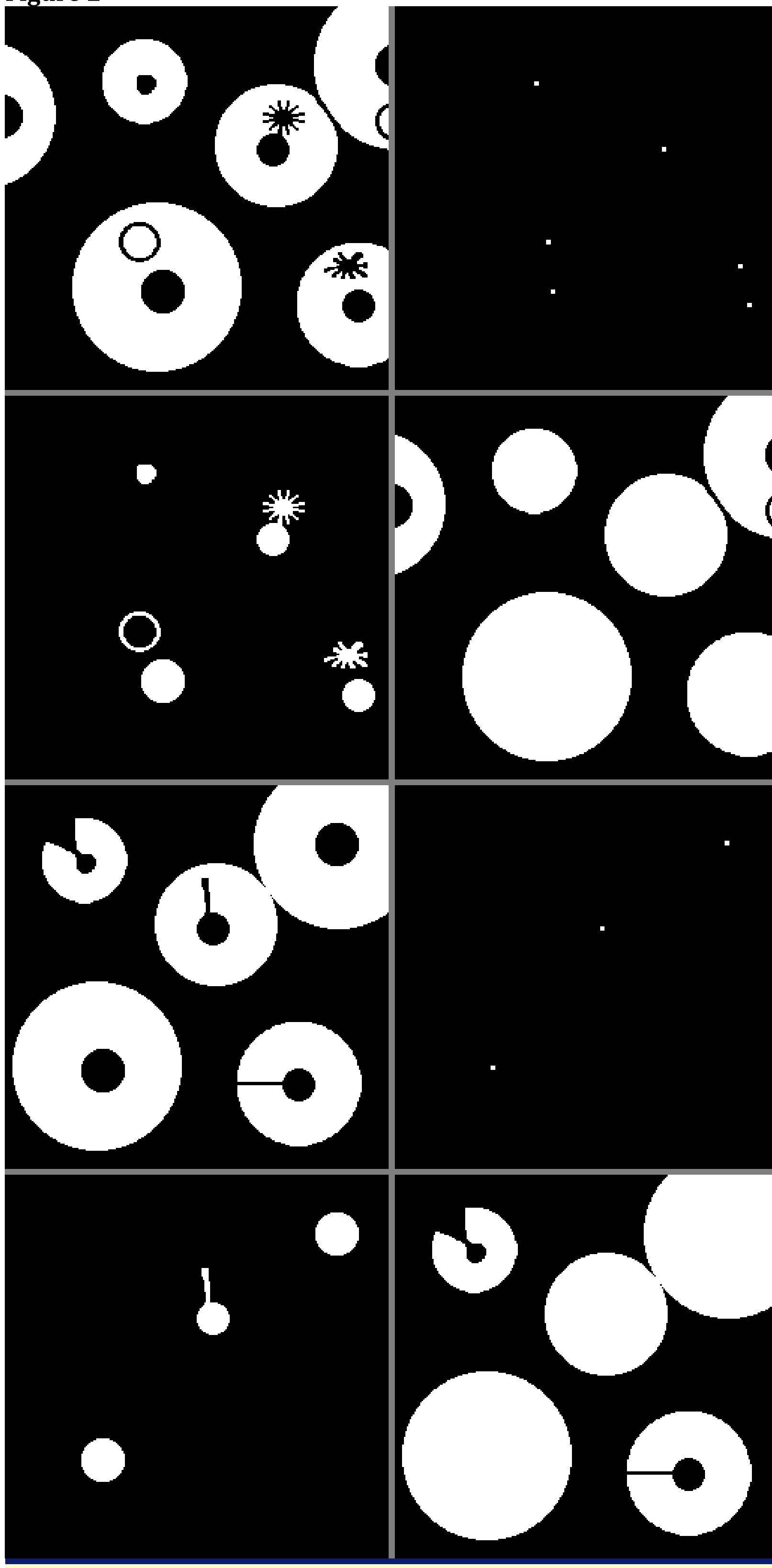

Figure 2 Results for Binary Images '04' and '05' using SMFA and SE='+'. For Image '04', 1st Row: Left, Source Image; Right, Marker Image with 6 Points (Holes). 2nd Row: Left, Filled Holes; Right, Source Image with Holes Filled. For Image '05', 3rd and 4th Rows: Same Clockwise Sequence as in Previous Binary Image. Marker Image has 3 Points (Holes).

Figure 3

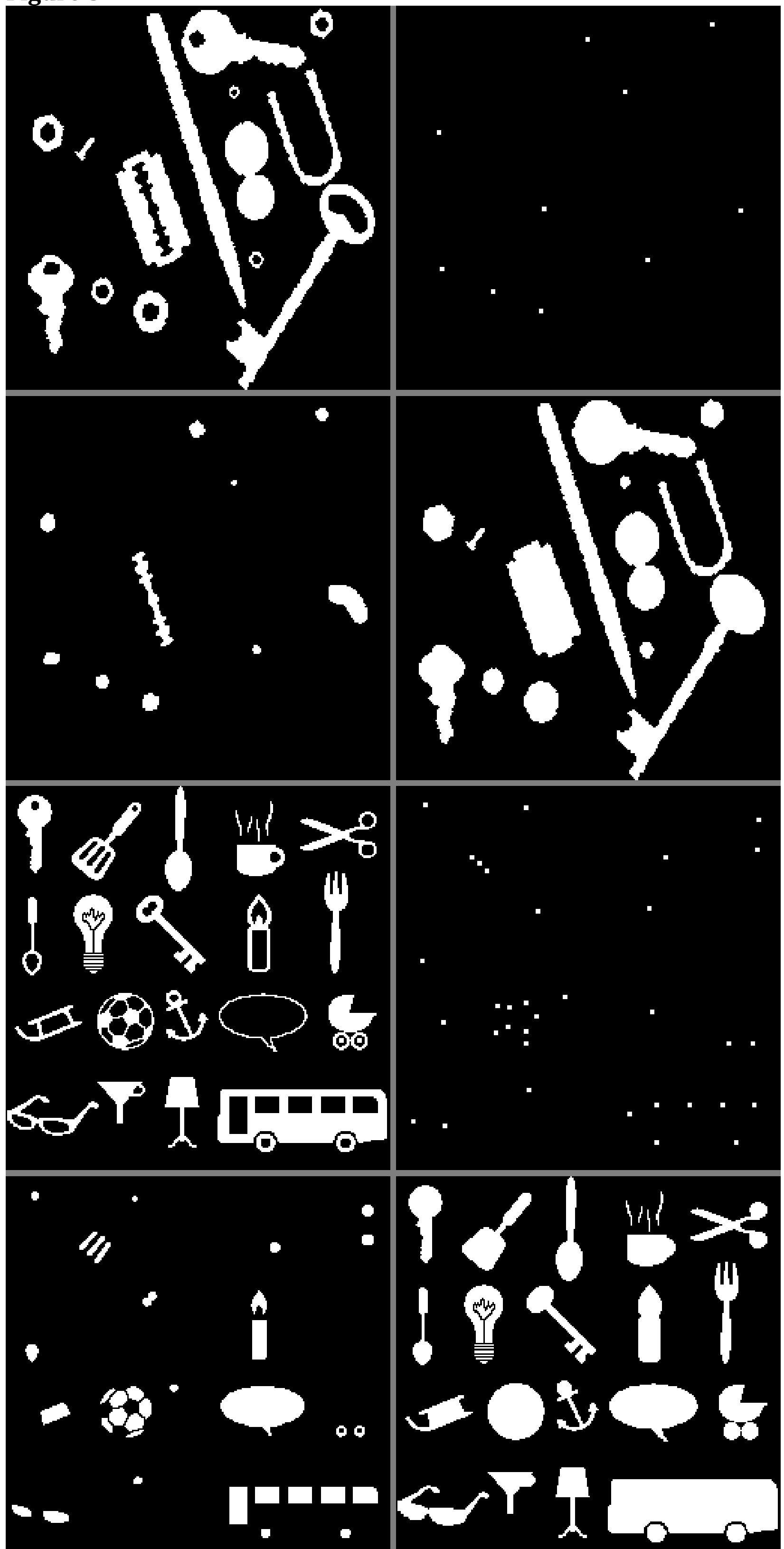

Figure 3 Results for Binary Images '06' and '07' using SMFA and SE='+'. For Image '06', 1st Row: Left, Source Image; Right, Marker Image with 10 Points (Holes). 2nd Row: Left, Filled Holes; Right, Source Image with Holes Filled. For Image '07', 3rd and 4th Rows: Same Clockwise Sequence as in Previous Binary Image. Marker Image has 34 Points (Holes).

Figure 4

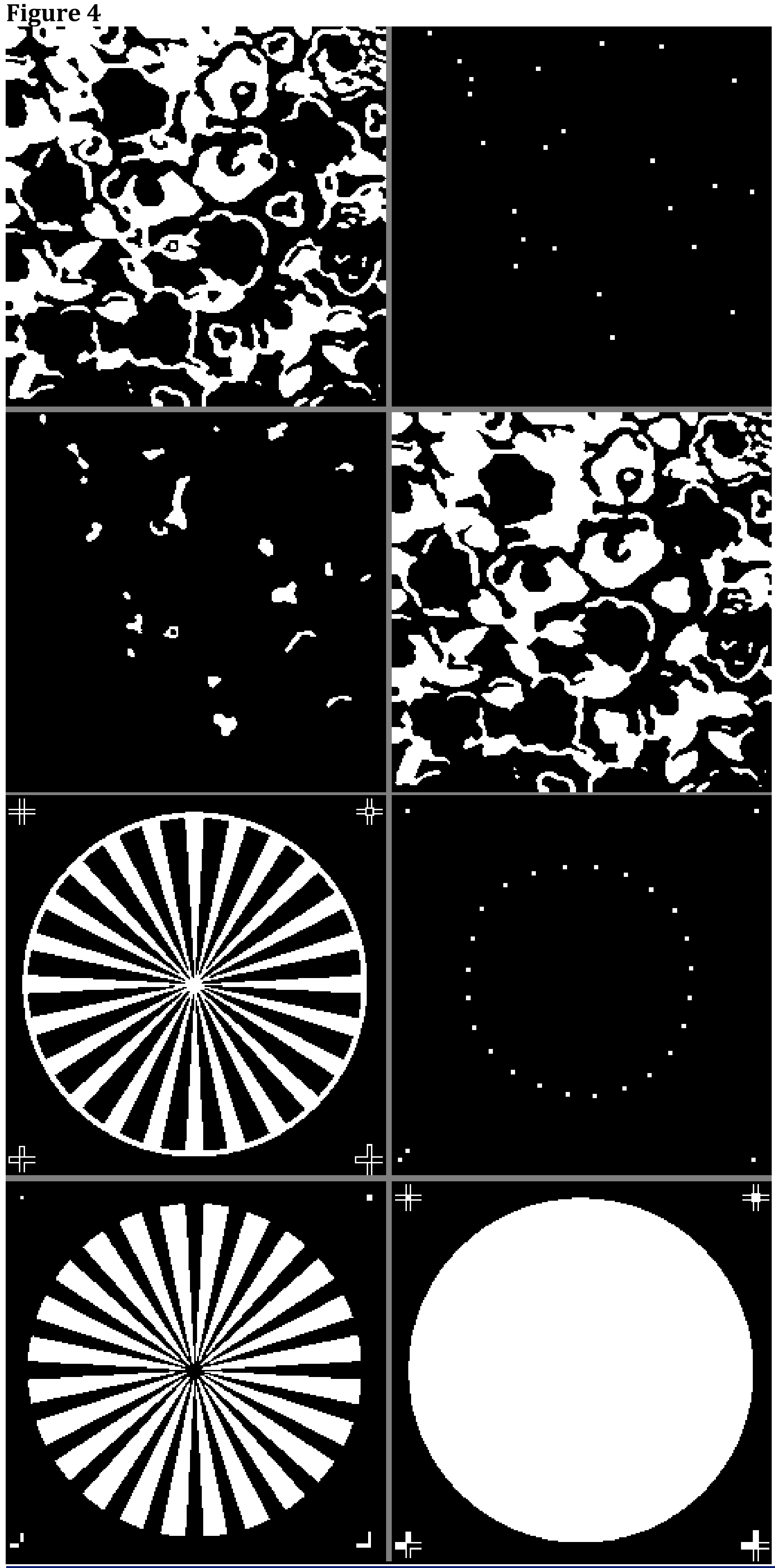

Figure 4 Results for Binary Images '09' and '11' Using SMFA and SE='+'. For Image '09', 1st Row: Left, Source Image; Right, Marker Image with 23 Points (Holes). 2nd Row: Left, Filled Holes; Right, Source Image with Holes Filled. For Image '11', 3rd and 4th Rows: Same Clockwise Sequence as in Previous Binary Image. Marker Image has 29 Points (Holes).

Figure 5

Figure 5 Results for Binary Images ‘13’ and ‘14’ Using SMFA and SE=‘+’. For Image ‘13’, 1st Row: Left, Source Image; Right, Marker Image with 20 Points (Holes). 2nd Row: Left, Filled Holes; Right, Source Image with Holes Filled. For Image ‘14’, 3rd and 4th Rows: Same Clockwise Sequence as in Previous Binary Image. Marker Image has 57 Points (Holes).

Figure 6

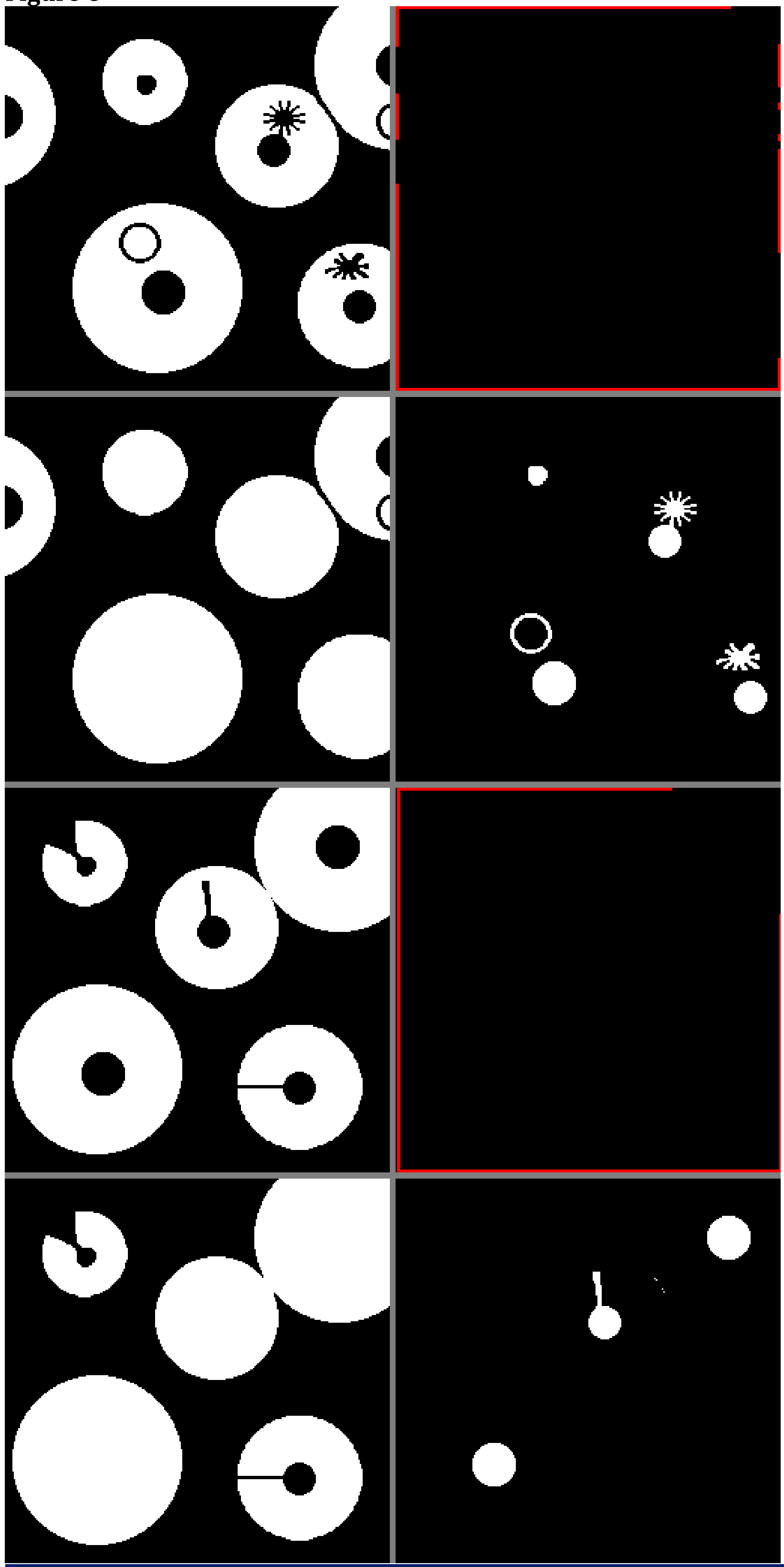

Figure 6 Results for Binary Images '04' and '05' Using UMFA and SE='+'. For Image '04', 1st Row: Left, Source Image; Right, Marker Image with Border Points (Red Color). 2nd Row: Left, Source Image with Holes Filled; Right, Filled Holes. For Image '05', 3rd and 4th Rows: Same Clockwise Sequence as in Previous Binary Image. Marker Image Shows Border Points in Red.

Figure 7

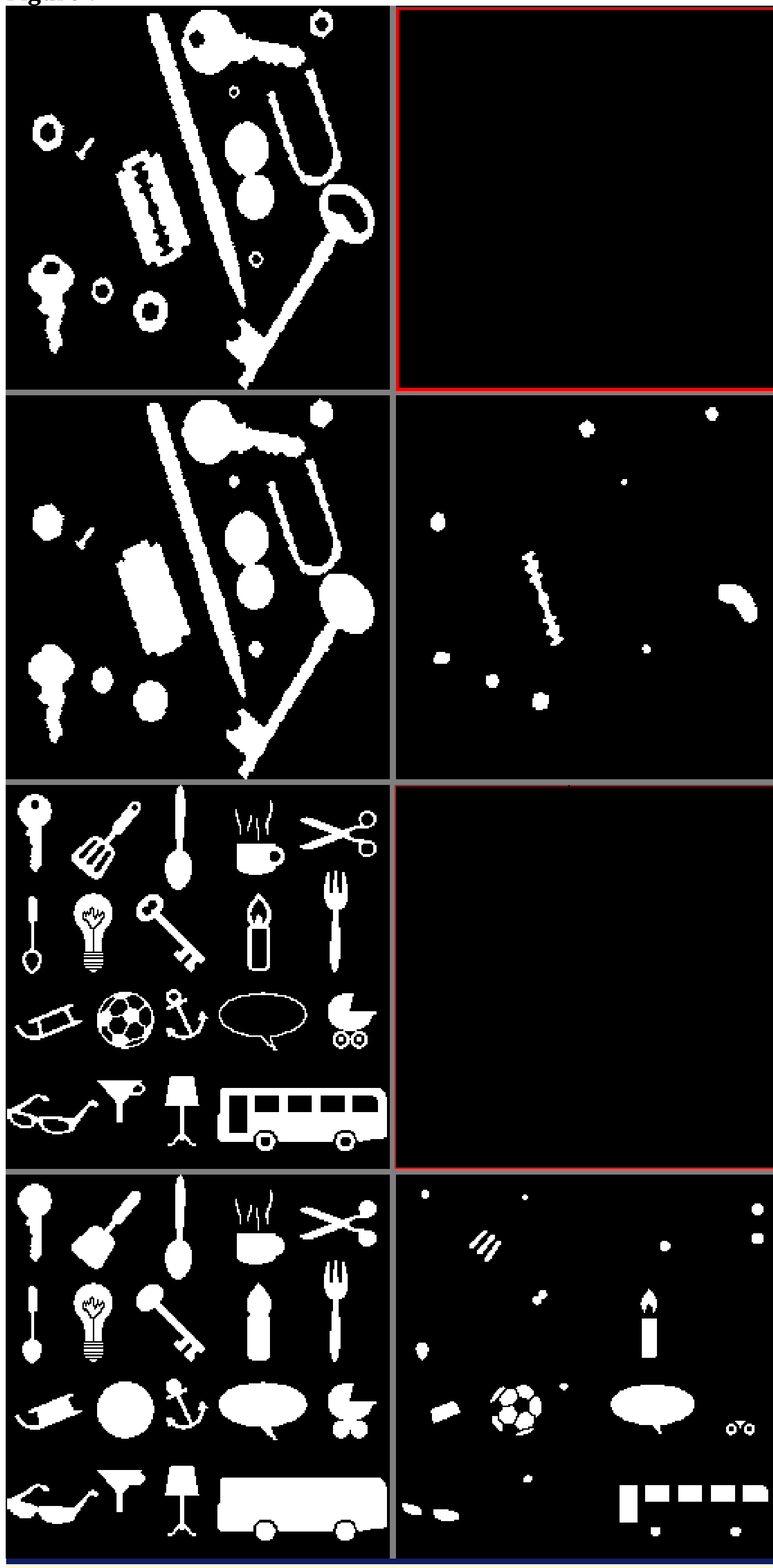

Figure 7 Results for Binary Images '06' and '07' Using UMFA and SE='+'. For Image '06', 1st Row: Left, Source Image; Right, Marker Image with Border Points (Red Color). 2nd Row: Left, Source Image with Holes Filled; Right, Filled Holes. For Image '07', 3rd and 4th Rows: Same Clockwise Sequence as in Previous Binary Image. Marker Image Shows Border Points in Red.

Figure 8

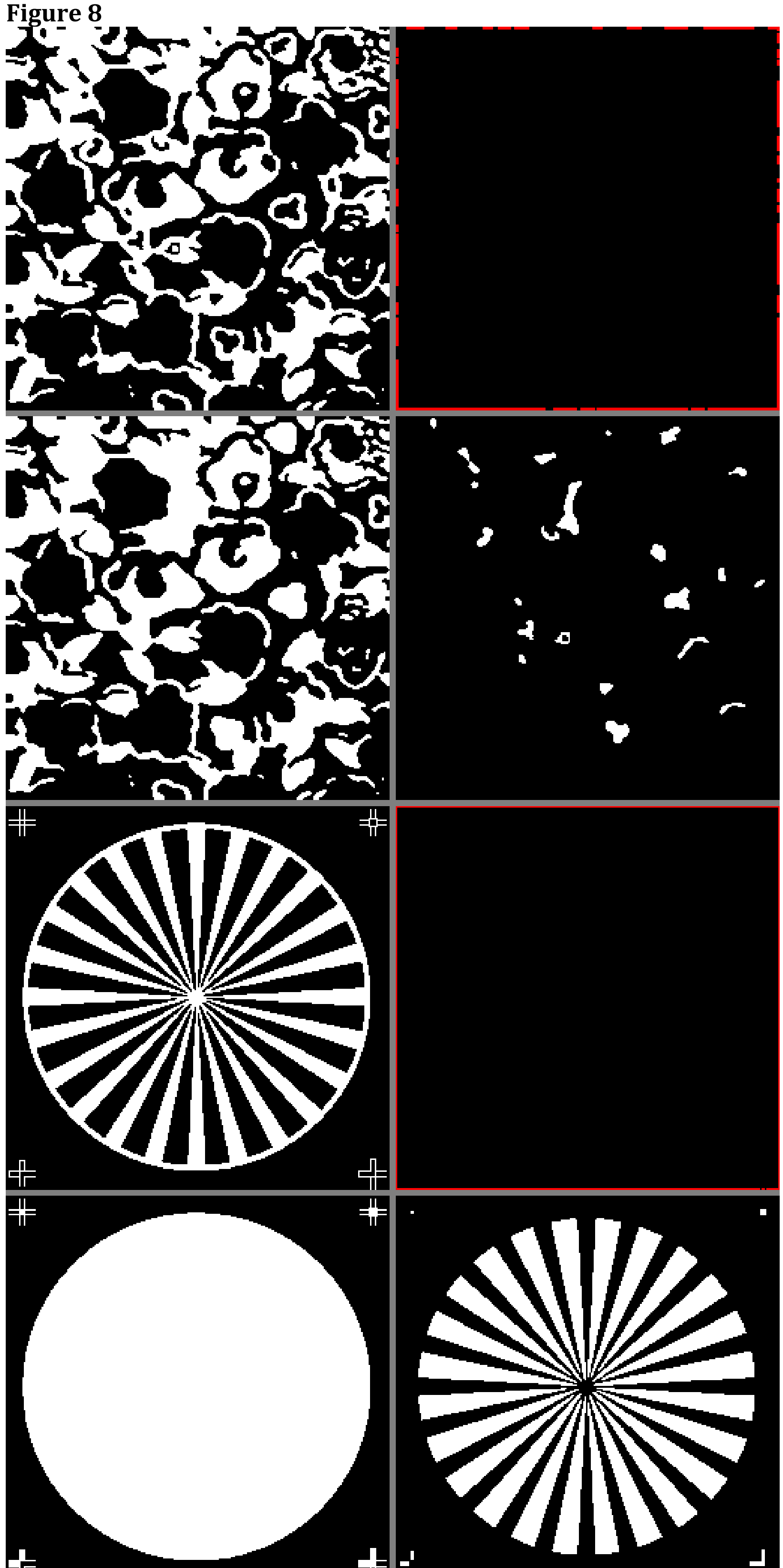

Figure 8 Results for Binary Images '09' and '11' Using UMFA and SE='+'. For Image '09', 1st Row: Left, Source Image; Right, Marker Image with Border Points (Red Color). 2nd Row: Left, Source Image with Holes Filled; Right, Filled Holes. For Image '11', 3rd and 4th Rows: Same Clockwise Sequence as in Previous Binary Image. Marker Image Shows Border Points in Red.

Figure 9

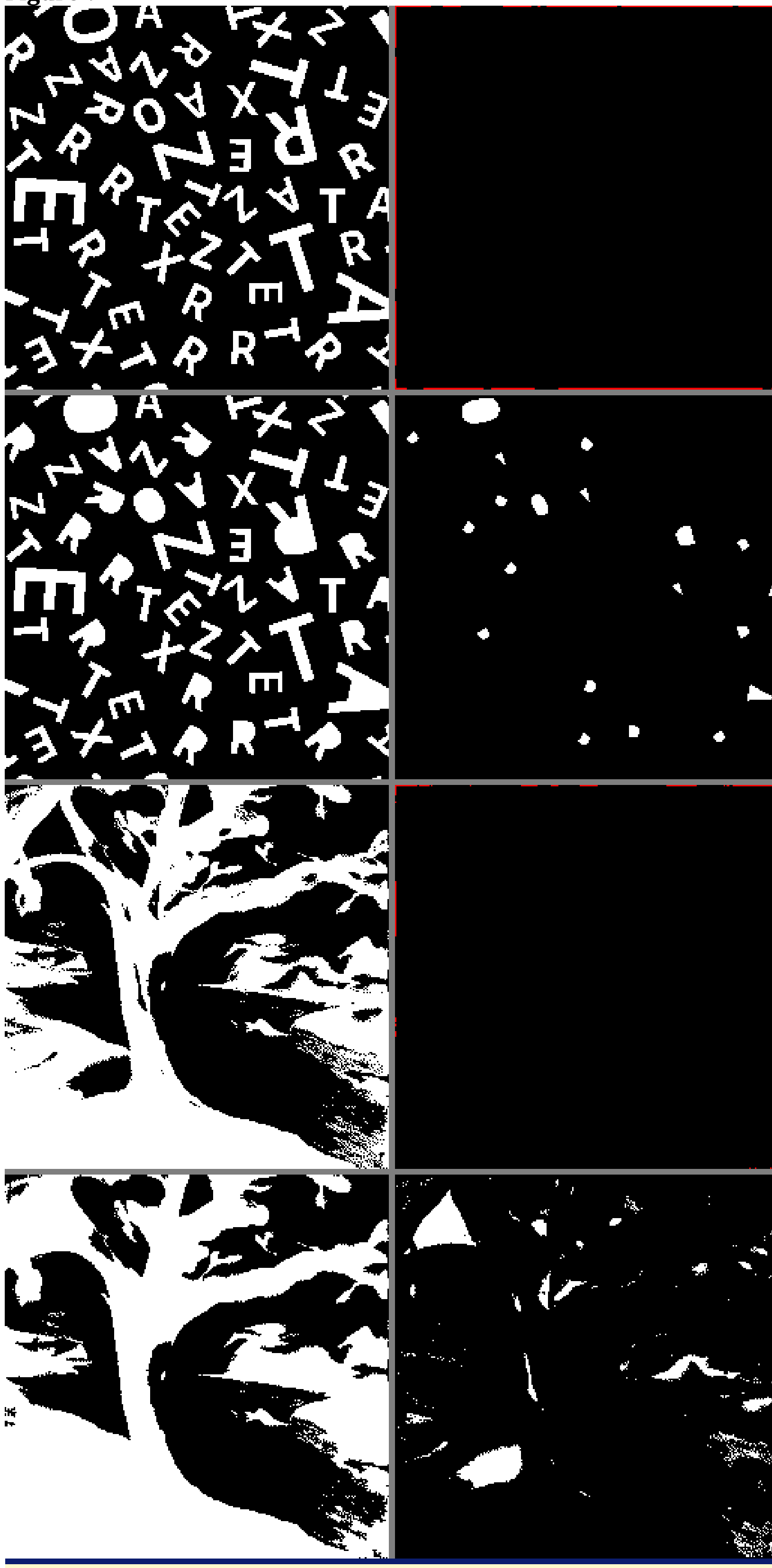

Figure 9 Results for Binary Images '13' and '14' using UMFA and SE='+'. For Image '13', 1st Row: Left, Source Image; Right, Marker Image with Border Points (Red Color). 2nd Row: Left, Source Image with Holes Filled; Right, Filled Holes. For Image '14', 3rd and 4th Rows: Same Clockwise Sequence as in Previous Binary Image. Marker Image Shows Border Points in Red.

Table 2

Table 2 Count Iteration k for Each Test Binary Image Using Morphological Hole Filling

Test Image	Holes	SMFA '+'	SMFA '■'	UMFA '+'	UMFA '■'
'00'	2	9	7	13	13
'01'	1	50	34	103	103
'02'	14	12	9	287	255
'03'	15	20	16	303	245
'04'	6	49	33	261	255
'05'	3	41	34	249	249
'06'	10	43	32	315	255
'07'	34	35	202 §	273	255
'08'	13	23	17	331	233
'09'	23	36	340 §	461	329
'10'	43	10	138 §	285	255
'11'	29	111	75	91	91
'12'	30	5	4	263	255
'13'	20	19	13	301	257
'14'	57	59	133	757	291
'15'	6	330	305	255	243

Comparing the iteration count in Table 2 between the 3rd and 5th columns one can see that the *k* values obtained with the SMFA '+' are less than those obtained by applying the UMFA '+', except for test images '11' and '15'. A similar comparison occurs between the 4th and 6th columns, where *k* values are greater for the UFMA '■' than for the SFMA '■', except for test images '09' and '15'. In general, the number of iterations required by the SFMA is much less than the number needed by the UFMA. The difference, as explained earlier, lies in the manner the marker images are built, i. e., interactively versus autonomously. However, the greater advantage of morphological recontruction from border points against conditional dilation based on seed points within holes is that, the first one as an automatic procedure does not require user intervention. Standard actual computer equipment spends *milliseconds* even for greater values of *k* such as those obtained with the UFMA and is independent of the number of holes. In disadvantage, *minutes* are consumed, before applying the SFMA, in preparing a marker image that depends on the number of holes and their spatial location.

An important remark is in order. In column 4, the *k* value for test images '07','09' and '10' has the symbol '§' meaning that "locally" there are pixels which are 8-connected to the background and therefore the use of the box '■' as SE, does not work correctly in treating single pixels as part of a hole. Hence, although convergence is reached, the image results fail to be useful. Finally, as a rule of thumb, both SFMA '+' and UFMA '+' can be used securely in practical applications, the second being the best due to its conceptual characteristics.

5. CONCLUSIONS

In this paper, the computational performance between supervised and unsupervised morphological hole filling algorithms has been analysed mathematically using explicit and detailed arguments based on set mathematical morphology. In addition, a representative collection of binary test images were used for showing qualitatively image results obtained by running both type of algorithms as well as quantitative numerical results obtained by keeping track of the total number of iterations required for convergence. Future work contemplates, for example, the study of possible correlations between the number of holes and the number of iterations needed.

CONFLICT OF INTERESTS

None.

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REFERENCES

Beucher, N. & Beucher, S. (2012). Mamba: Mathematical Morphology Library Image for Python Programming Language.

Bloch, I., Heijmans, H., & Ronse, C. (2007). Mathematical Morphology. In M. Aiello, I. Pratt-Hartmann, & J. Van Benthem (Eds.), Handbook of Spatial Logic. (Ch. 14, 857-875). Springer.

Dougherty, E. R. (1992). An Introduction to Morphological Image Processing. SPIE Tutotial Texts in Optical Engineering, Bellingham, Washington, USA, 9, 39-42.

Fanfeng, Z. & Wei, F. (2010). Hole Filling Algorithm Based on Contours Information. In Proceedings of 2nd International Conference on Information Science and Engineering, Hangzhou, China. IEEE Xplore, https://doi.org/10.1109/ICISE.2010.5691941

Gonzalez, R.C. & Woods R.E. (2018). Morphological Image Processing. In Digital Image Processing, 4th Global ed. (Ch. 9, 653-655 & 667-674). Pearson, New York, NY, USA.

Gonzalez, R.C., Woods, R.E., & Eddins S.L. (2020). Morphological Image Processing. In Digital Image Processing Using MATLAB, 3rd ed. (Ch. 10, 614-618). Gatesmark Publishing.

Géraud, T., Talbot, H., & Van Droogenbroeck, M. (2010). Algorithms for Mathematical Morphology. In L. Najman & H. Talbot (Eds.), Mathematical Morphology: From Theory to Application. (Ch.12, 323-352). ISTE/Wiley & Sons, UK/USA. https://doi.org/10.1002/9781118600788.ch12

Haralick, R.M., Sternberg, S.R., & Zhuang X. (1987). Image Analysis Using Mathematical morphology. IEEE Trans. on Pattern Analysis and Machine Intelligence, PAMI-9(4), 532-550, https://doi.org/10.1109/TPAMI.1987.4767941

Hasan, M.M. & Mishra, P.K. (2012). Improving Morphology Operation for 2D Hole Filling Algorithm. International Journal of Image Processing (IJIP), 6(1), 1-12.

He, Y., Hu, T., & Zeng, D. (2019). Scan-Flood Fill (SCAFF): An Efficient Automatic Precise Region Filling Algorithm for Complicated Regions, 761-769. 2019 IEEE/CVF Conference on Computer Vision and Pattern Recognition Workshops (CVPRW), Long Beach, CA, USA. IEEE Xplore, https://doi.org/10.1109/CVPRW.2019.00104

Maragos, P. (1987). Tutorial on Andvances in Mophological Image Processing and analysis. Optical Engineering, 26(7), 623-632, https://doi.org/10.1117/12.7974127

Najman, L. & Talbot, H. (2010). Introduction to Mathematical Morphology. In L. Najman and H. Talbot (Eds.), Mathematical Morphology: From Theory to Application. (Ch. 1, 3-33). ISTE/Wiley, Great Britain/USA, https://doi.org/10.1002/9781118600788.ch1

Pitas, I. (2000). Shape Description. In Digital Image Processing Algorithms and Applications, 361-369. John Wiley & Sons, New York, USA.

Rivest, J-F., Soille P., & Beucher S. (1993). Morphological Gradients. Journal of Electronic Imaging, 2(4), 326-336. https:/doi.org/10.1117/12.159642.

Serra, J. (1986). Introduction to Mathematical Morphology. Computer Vision, Graphics, and Image Processing, 35, 283-305, https://doi.org/10.1016/0734-189X(86)90002-2

Soille, P. (2004). Geodesic Transformations. In Morphological Image Analysis: Principles and Aplications, 2nd ed. (Ch. 6, 183-216). Springer-Verlag, Berlin-Heidelberg, Germany.

Valdiviezo-N., J.C., Urcid, G., & Edwin, L. (2017). Digital Restoration of Damaged Color Documents Based on Hyperspectral Imaging and Lattice Associative Memories. Signal, Image and Video Processing (SIViP), 11, 937-944. https://doi.org/10.1007/s11760-016-1042-y

Van Droogenbroeck, M. (1994). On the Implementation of Morphological Operations. In J. Serra & P. Soille (Eds.), Mathematical Morphology and Its Applications to Image Processing, 241-248. Kluwer Academics, The Netherlands.

Vincent, L. (1992). Morphological Algorithms. In E.R. Dougherty (Ed.), Mathematical Morphology in Image Processing, 255-288. CRC-Press, Boca Raton, FL, USA. https://doi.org/10.1201/9781482277234

Vincent, L. (1993). Morphological Grayscale Reconstruction in Image Analysis: Applications and Efficient Algorithms. IEEE Transactions on Image Processing, 2(2), 176-201. https://doi.org/10.1109/83.217222

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RAMA: PROGRAMAS DE COMPUTACION

TITULAR: INSTITUTO TECNOLOGICO SUPERIOR DE SAN ANDRES TUXTLA (CON FUNDAMENTO EN EL ARTICULO 83 DE LA L.F.D.A. EN RELACION CON EL ARTICULO 46 DEL R.L.F.D.A.)

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Ciudad de México, a 14 de noviembre de 2024

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