Detection of Freestyle Swimming Technique Mistakes Using Computer Vision Technology: A Case Study of Students Faculty Sports Science

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ABSTRACT:
This study aims to analysed front crawl stroke technical mistakes utilizing computer vision technology. Conventional evaluation of swimming technique still faces various limitations, such as the subjectivity of assessment and the difficulty of observing movements in detail. Therefore, the application of computer vision technology is expected to provide a more objective and accurate analysis of movement. This study employs a quantitative approach using a descriptive-evaluative method and a cross-sectional study design. The research sample consisted of 300 students from students at the Faculty of Sports Science, Medan State University, comprising 246 male students and 54 female students. The dataset consists of video recordings of students swimming the freestyle stroke. Afterwards, the videos were analyzed using a computer vision system based on pose estimation. Data analysis was conducted using descriptive and inferential statistics to identify types of technical mistakes and measure the system's accuracy level. The results of the study show that the most common technical error was unsynchronized arm and leg coordination at 32.3%, followed by lifting the head too high while breathing at 30.7%, irregular leg kicks at 28.3%, a hip position that is too low at 27.0%, excessive head rotation at 26.0%, insufficient arm pull at 24.7%, and an imperfect arm push at 23.0%. The system testing results showed an accuracy of 90.8%, precision of 89.5%, recall of 90.1%, and an F1-score of 89.8%. In addition, the Intraclass Correlation Coefficient (ICC) was 0.87. This indicates a high level of agreement between the system's detection results and the experts' assessments. Therefore, computer vision technology serves as an effective alternative tool for evaluating freestyle swimming learning in higher education institutions.

Keywords: Computer Vision, freestyle swimming, motion analysis, technical mistakes

1. Introduction

Front crawl is the most widely practiced swimming stroke and commonly the first fundamental technique learned by novice swimmers (Widmer et al., 2025). This stroke develops critical skills, including proper body position, breath control, and arm-leg

coordination, which are essential for swimming proficiency. In addition, many of its principles can be applied to other swimming styles, such as backstroke, breaststroke, and butterfly. Given its central role in developing fundamental skills in the water and supporting the learning of more advanced techniques, effective instruction in the crawl stroke should be considered a high priority in swimming training programs (Wang, 2025).

Technical mistakes in freestyle swimming are still commonly observed among college students, particularly in the body position, arm stroke, leg kick, and breathing phases. Common mistakes include a head position that is raised too high, thereby increasing water resistance; suboptimal body rotation; and unsynchronized coordination of arm and leg movements. Additionally, many students take breaths by excessively turning their heads, which can disrupt body balance and the continuity of the stroke. These mistakes result in reduced movement efficiency, decreased swimming speed, and increased energy expenditure (Kolmogorov et al., 2021). Therefore, early identification of technical mistakes is a crucial step in improving the quality of learning and students' swimming performance through the provision of appropriate, evidence-based feedback (Morais et al., 2021).

Manual observation remains a common method used by instructors and coaches to evaluate students' swimming skills. Through direct observation, instructors can identify various technical mistakes, such as a body position that lacks streamlining, unsynchronized coordination of arm and leg movements, and mistakes in breathing technique. However, this method has several limitations that can affect the objectivity and accuracy of the assessment. In fast-paced and repetitive swimming movements, instructors or coaches often find it difficult to observe every detail of the movement comprehensively at once. Consequently, some technical mistakes that occur over a brief duration may be missed (Trindade et al., 2024).

Furthermore, manual observation is prone to subjectivity in assessment. Differences in experience, competency levels, and focus between coaches can result in different interpretations of the same movement. This condition has the potential to reduce the consistency and reliability of technique evaluation. According to (Edriss et al., 2025) Silva et al., human observation-based assessments often show significant variation in results, especially when used to analyze complex and multidimensional sports movements.

Another limitation is the difficulty in obtaining accurate quantitative data on biomechanical parameters, such as joint angles, movement speed, phase duration, and coordination between body segments. This information is crucial for understanding technique quality and determining appropriate improvement strategies. (Morais et al., 2021) explain that biomechanical data-based technique analysis can provide a more comprehensive picture of movement efficiency and swimming performance than visual observation alone. Therefore, the use of technologies such as computer vision is a promising alternative to improve the objectivity, accuracy, and effectiveness of swimming skill evaluation in modern learning and coaching (Araújo et al., 2021).

In addition, the results of manual observations are highly dependent on the experience, competence, and perceptions of the individual observer. Differences in background and skill level can lead to variations in the interpretation of movements and the assessment of student performance, resulting in less consistent assessment reliability (Edriss et al., 2025). Another limitation is the lack of quantitative data that can be used to analyze biomechanical aspects in detail, such as joint angles, movement speed, and body coordination patterns. The use of computer vision-based technology and digital motion analysis offers a promising alternative for enhancing the objectivity, accuracy, and efficiency of swimming skill evaluation in modern sports education (Ferreira et al., 2016; Pietraszewski et al., 2025).

Advances in Artificial Intelligence (AI) and Computer Vision over the past few years have brought significant changes to the field of sports

motion analysis. This technology enables the automatic identification, tracking, and evaluation of athletes' movements through digital image and video processing. By utilizing machine learning and deep learning algorithms, Computer Vision is capable of detecting body position, joint angles, movement patterns, and technical mistakes more objectively and consistently than manual observation (Ashimalu et al., 2023). In the context of sports, this technology has been used to analyze athlete performance in swimming, track and field, soccer, and basketball to support data-driven coaching decisions (Claudino et al., 2019). In addition to improving the accuracy of technical evaluations, AI also enables real-time feedback, thereby accelerating the motor learning process and enhancing athletes' skills. The integration of AI and Computer Vision is one of the key innovations in the development of modern sports science (Baca et al., 2022).

Advances in computer vision technology offer significant opportunities to improve the quality of swimming technique evaluations. Unlike manual observation, which relies heavily on the experience and perception of instructors or coaches, computer vision can automatically analyze movements through video processing and the identification of anatomical landmarks on the body. This technology enables the measurement of biomechanical parameters—such as joint angles, body position, coordination of arm and leg movements, and breathing patterns—in a more objective and consistent manner (Araújo et al., 2021). In swimming instruction, the use of Computer Vision can help identify technical mistakes that are difficult to observe directly due to the speed of movement and the limitations of human observation. Additionally, AI-based systems can provide rapid, data-driven feedback, thereby supporting a more effective learning process (Claudino et al., 2019). The ability to generate accurate quantitative data positions Computer Vision as a promising innovation in the evaluation of swimming skills and the performance development of athletes and sports students (Baca et al., 2022).

Freestyle swimming technique mistakes are still commonly found among students at the Faculty of Sports Science, Medan State University. These mistakes generally involve a body position that is not streamlined enough, suboptimal coordination of arm and leg movements, and improper breathing technique. These conditions result in less efficient swimming movements, increased water resistance, and reduced swimming performance. The high frequency of technical mistakes highlights the need for more objective learning evaluations and the use of technology to help identify and correct students' movements more accurately.

2. Methodology

This study adopted a quantitative approach using a descriptive-evaluative method aimed at detecting and analyzing mistakes in students' freestyle swimming movements using computer vision technology. The quantitative approach was chosen because it allows for objective measurement of the observed movement variables and generates numerical data that can be statistically analyzed. According to (Creswell, 2003) Creswell and, quantitative research is used to test phenomena through the collection of measurable data, thereby yielding conclusions that can be generalized.

The research design used was a cross-sectional study, with data collection conducted over a single observation period. All study participants were asked to swim freestyle in a designated lane of the swimming pool, and their movements were recorded using a high-resolution digital camera. The resulting video was then analyzed using a Computer Vision system based on pose estimation to identify technical mistakes in several key components of the freestyle stroke, namely body alignment, arm stroke, flutter kick, movement coordination, and breathing technique.

The study population consisted of students in the Faculty of Sports Science at the State University of Medan who were enrolled in a swimming course during the academic year in which the study was conducted. The study sample comprised 300 students selected using purposive

sampling; specifically, students who had completed basic swimming instruction and were willing to participate as research respondents. This sample size was deemed sufficient to yield data representative of the population's characteristics (Giulietti et al., 2023; Sugiyono, 2022).

Development of a model for identifying freestyle swimming movements using a machine learning algorithm, specifically a convolutional neural network (CNN) (Giulietti et al., 2023). A convolutional neural network (CNN) is a type of artificial neural network in deep learning that is specifically designed to process image data. The CNN algorithm works by automatically extracting key features from images through a series of layers for the purpose of classification or object detection. The Convolutional Neural Network (CNN) model was selected as the primary algorithm in the development of the swimming motion detection system because CNNs excel at recognizing visual patterns, processing spatial features, and mapping motion structures in depth (Chern et al., 2025). Compared to classical image processing methods, CNNs can automatically extract key features without requiring manual feature engineering (handcrafted features). CNN architecture has also proven effective in tasks such as pose estimation, motion classification, and sports motion detection, as demonstrated by previous research. Its ability to handle variations in camera angles, lighting changes, and water movement dynamics makes it more reliable for analyzing freestyle swimming techniques. Therefore, CNN is the most relevant and robust algorithm for generating an accurate, objective, and stable swimming technique assessment model. Figure 2.1 presents the workflow of the CNN algorithm. This study uses only libraries available in the Python programming language.

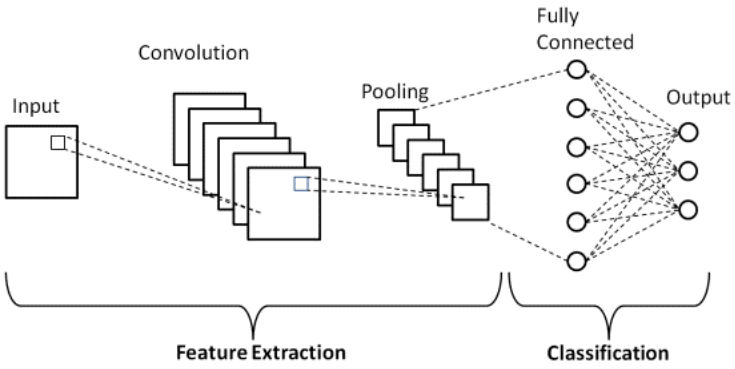

Figure 2.1. Flowchart Algorithm CNN

The model generated by the CNN algorithm recognizes the technical components of the freestyle swimming stroke, including body position, arm movements, leg movements, and coordination. The model was trained using an annotated dataset and its performance was evaluated using metrics such as accuracy, precision, and recall to ensure the system can objectively detect technical mistakes. The next step is integrating the trained model into an Android-based mobile application. This process involves converting the model to a format compatible with mobile devices, such as TensorFlow Lite, so it can run efficiently on smartphones. The application is then designed with a user-friendly interface, allowing instructors and students to upload swimming videos, run automatic analysis, and receive feedback in the form of scores or technical recommendations. This integration ensures that the real-time feedback function operates optimally on mobile devices. The final stage involves testing the application on Android devices to ensure that all functions run stably and that the computer vision model can accurately analyze movements in the context of swimming instruction. Thus, this entire process results in an innovative, practical, and ready-to-implement prototype of a freestyle swimming assessment system for widespread use in sports education.

The main tools used in this study consisted of hardware and software. The hardware included a smartphone, a tripod, a laptop for data processing, and video storage devices. Meanwhile, the software used is a Computer Vision application based on MediaPipe Pose, which is capable of automatically detecting anatomical landmarks in each video frame. In addition to technology-based instruments, this study also utilized a freestyle swimming observation sheet developed based on swimming skill indicators from the Fédération Internationale de Natation (FINA). The observation sheet was used by three swimming experts as the gold standard to validate the system's detection results. The observed indicators included head position, body position, entry phase, pull phase, push phase, leg movement, movement coordination, and breathing technique. According to (Konczak, 2007), the use of more than one instrument can improve the validity and reliability of sports research data.

The research process began with the recording of freestyle swimming videos of all participants. The camera was positioned at the side of the pool to obtain the optimal shooting angle. The videos were then processed using computer vision algorithms to detect body landmarks and calculate biomechanical parameters, such as the angles of the shoulders, elbows, hips, and knees. The data obtained was then compared with the ideal swimming technique model established by experts.

The data were analyzed using descriptive and inferential statistics. Descriptive statistics were used to determine the frequency and percentage of technical mistakes for each movement indicator. Furthermore, the accuracy of the computer vision system was analyzed using accuracy, precision, recall, and F1-score metrics. The Intraclass Correlation Coefficient (ICC) was used to assess the level of agreement between the system's detection results and expert evaluations (Martínez Pérez & Pérez Martin, 2023). According to (Field, 2017), the ICC is an appropriate method for measuring the level of agreement among raters on quantitative data. All statistical analyses were performed using the latest version of SPSS software with a significance level of 0.05. The results of the analysis were used to determine the ability of Computer Vision technology to detect mistakes in freestyle swimming movements objectively and accurately among students in the Faculty of Sports Science.

3. Results

This study aims to detect mistakes in freestyle swimming technique using computer vision technology among students at the Faculty of Sports Science. The study employed a descriptive-evaluative approach with a cross-sectional design, meaning data collection was conducted over a single observation period. A total of 300 students participated in this study, consisting of 246 male students (82.0%) and 54 female students (18.0%). All respondents had taken a swimming course and were able to perform the freestyle stroke according to the instructions provided.

The results of the descriptive analysis show that the majority of respondents were male students. This sample composition reflects the characteristics of students in the Faculty of Sports Science, which is generally dominated by male students. All respondents performed a 25-meter freestyle swimming test, which was recorded using a high-resolution digital camera. The video data was then processed using Computer Vision technology based on pose estimation to identify technical mistakes in several movement indicators. Based on the results of the Computer Vision system analysis, it was found that most students still made various technical mistakes in freestyle swimming. The most dominant mistakes occurred in the breathing technique. A total of 214 students (71.3%) were identified as making mistakes while taking a breath, such as tilting their heads too high and delaying the return of the head to the water. These mistakes cause a loss of body balance and increase drag while swimming.

Regarding the indicator of movement coordination, 198 students (66.0%) exhibited a lack of synchronization between arm and leg movements and their breathing patterns. This condition resulted in reduced movement

efficiency and decreased swimming speed. Furthermore, regarding body position, 186 students (62.0%) were unable to maintain a streamlined body position. Most students had their hips positioned too low, which increased water resistance.

Regarding arm movement indicators, 173 students (57.7%) made mistakes, primarily during the pull and push phases. The most common error was a suboptimal backward push of the arms, which reduced propulsive force. Meanwhile, regarding leg movement, 162 students (54.0%) performed leg kicks that lacked rhythm and failed to provide effective forward propulsion.

Table 1. Results of Mistakes Detection in Freestyle Swimming Techniques Using Computer Vision

NO	Technical Indicators	Number of Students Making Mistakes	Percentage (%)
1	Breathing Techniques	214	71,3
2	Coordination of Movement	198	66
3	Body Position (Streamline)	186	62
4	Arm Movement	173	57,7
5	Limb Movement	162	54

These findings indicate that breathing techniques and movement coordination are the aspects that require the most attention in learning the freestyle stroke. Computer vision can also detect seven types of freestyle swimming mistakes: head raised too high during breathing (92 students, 30.7%), excessive head rotation (78 students, 26%), Hips positioned too low (81 students, 27%), Insufficient arm pull (74 students, 24.7%), Incomplete arm drive (69 students, 23%), Irregular leg kick (85 students, 28.3%), and Asynchronous arm-leg coordination (97 students, 32.3%).

Table 2. Distribution of Types of Technical Mistakes in the Freestyle Stroke.

No	Types of mistakes	Frequency	Percentage (%)
1	Head tilted back too far when breathing	92	30,7
2	Excessive head rotation	78	26
3	Hips positioned too low	81	27
4	Insufficient arm pull	74	24,7
5	Incomplete arm drive	69	23
6	Irregular leg kick	85	28,3
7	Asynchronous arm-leg coordination	97	32,3

To determine the system's ability to detect movement mistakes, the results of the computer vision analysis were compared with the observations of three swimming experts, who

served as the gold standard. The analysis showed that the system achieved an accuracy of 90.8%, a precision of 89.5%, a recall of 90.1%, and an F1-score of 89.8%.

Table 3. Results of the Computer Vision System Accuracy Analysis

No	Evaluation Parameters	Mark (%)
1	Accuracy	90,8
2	Precision	89,5
3	Recall	90,1
4	F1-Score	89,8

Furthermore, the reliability test using the Intraclass Correlation Coefficient (ICC) yielded a value of 0.87 with a significance level of $p < 0.05$. This value indicates a high level of agreement between the system's detection results and the expert's assessment. According to Field (2018), an ICC value above 0.75 indicates strong reliability and can serve as evidence that the instrument has good consistency.

Table 4. Results of the Comparison Test Between Computer Vision and Expert Assessment

NO	Variable	Mark ICC	Interpretation
1	Body Position	0,85	High
2	Arm Movement	0,88	High
3	Limb Movement	0,84	High
4	Breathing Techniques	0,89	High
5	Coordination of Movement	0,9	Very high
	Average ICC	**0,87**	High

For a comparison of error rates based on gender shown in Table 5.

Table 5. Comparison of Mistakes Rates by Gender

No	Technical Indicators	Male (n=246)	Female (n=54)	Total (%)
1	Breathing Techniques	173	41	71,3
2	Coordination of Movement	163	35	66
3	Body Position	153	33	62
4	Arm Movement	141	32	57,7
5	Limb Movement	132	30	54

The results of this study demonstrate that computer vision technology can objectively and accurately detect mistakes in freestyle swimming technique. In addition to producing consistent data, the system is also capable of identifying movement mistakes that are difficult for lecturers

or coaches to directly observe. Therefore, the use of this technology has the potential to be a more effective, efficient, and data-driven alternative for evaluating swimming lessons within the Faculty of Sport Science.

4. Discussion

The results of the study show that Computer Vision technology is able to objectively and accurately detect various freestyle swimming technique mistakes in students of the Faculty of Sport Science. This finding indicates that the use of artificial intelligence-based technology can be an effective alternative in the process of evaluating swimming skills. Unlike conventional observation methods that rely heavily on the experience and subjectivity of lecturers or coaches, Computer Vision is able to automatically identify movement patterns through video analysis and pose estimation. This capability allows for more detailed, consistent, and data-driven technique evaluations.

Based on the research results, the most dominant error was found in the aspect of unsynchronized arm and leg coordination, with a percentage of 32.3%. This finding indicates that most students still experience difficulty integrating arm and leg movements during freestyle swimming. Motor coordination is a crucial component of swimming skills because it determines the efficiency of energy transfer during the swimming process. When coordination between the arms and legs is not harmonious, the resulting propulsive force is not optimal, resulting in decreased swimming speed. The results of this study are in line with the findings of (Seifert et al., 2014), who stated that motor coordination is a major factor in swimming efficiency because it affects the synchronization between propulsion and body balance in the water. Athletes with good motor coordination tend to be able to maintain swimming speed with lower energy expenditure than swimmers with poor motor coordination.

The next most common error found was raising the head too high when breathing, with a percentage of 30.7%. These results indicate that students still experience difficulty in implementing correct breathing techniques. In freestyle swimming, the breathing process should be done through minimal body rotation so that the body position remains parallel to the water surface. However, most students raise their heads too high, causing the hips to drop and increasing water resistance (drag force). According to (Morais et al., 2021), inefficient breathing techniques can disrupt body balance and reduce swimming performance by increasing resistance to forward movement. Therefore, breathing technique training requires special attention in swimming lessons in universities.

Furthermore, the study results showed that 28.3% of students performed unrhythmic leg kicks. Leg kicks in freestyle swimming help maintain body balance and contribute to propulsion. Inconsistent kicks will result in loss of rhythm and reduced swimming efficiency. This finding is supported by research by (Barbosa et al., 2011), which explains that synchronization between leg and arm movements plays a crucial role in maintaining body stability and increasing propulsive effectiveness during swimming. Therefore, developing leg coordination exercises needs to be an integral part of the learning process for basic swimming techniques.

Regarding body position, the study found that 27.0% of students had a hip position that was too low when swimming. This non-streamlined body position increases water resistance, resulting in greater energy expenditure. From a sports biomechanics perspective, a body position parallel to the water's surface is a key factor in determining swimming efficiency. This finding aligns with research by (Price et al., 2024), which states that good body position can significantly reduce drag and increase swimming speed. Therefore, the ability to maintain proper body position requires repeated practice to become an automatic movement pattern.

Other mistakes found included excessive head rotation during breathing (26.0%), suboptimal arm pull (24.7%), and incomplete arm thrust (23.0%). Although these percentages were lower than other indicators, these three aspects still significantly impacted the quality of swimming technique. The arm pull and push are the primary

sources of propulsion in freestyle swimming. If the pull and push phases are not performed optimally, the resulting propulsion will be reduced. According to (De Souza Castro et al., 2023), the effectiveness of arm movements is directly related to swimming speed because more than 80% of the propulsion force is generated through arm activity. Therefore, mistakes in the pull and push phases need to be immediately corrected through appropriate feedback.

One of the important findings in this study is the high level of accuracy of the Computer Vision system in detecting swimming technique mistakes. The analysis results showed an accuracy value of 90.8%, precision of 89.5%, recall of 90.1%, and F1-score of 89.8%. These values indicate that the system is able to identify technique mistakes with a very good level of accuracy. The high precision value indicates that most of the detected mistakes are truly technique mistakes, while the high recall value indicates the system's ability to detect almost all mistakes that occur. These results support the research of (Pietraszewski et al., 2025) which states that Computer Vision technology has a high capability in analyzing sports movements automatically and objectively.

Furthermore, the results of the suitability test using the Intraclass Correlation Coefficient (ICC) yielded a value of 0.87. This value indicates a high level of reliability between the system's detection results and the assessments of swimming experts. This finding strengthens the argument that Computer Vision technology can be used as an evaluation tool with a high level of consistency. (Usami et al., 2025) reported that an artificial intelligence-based motion analysis system was able to achieve a high level of agreement with the assessments of professional coaches, making it suitable for use in the evaluation process of sports techniques.

Overall, the results of this study indicate that computer vision technology is not only capable of accurately identifying mistakes in freestyle swimming technique but also provides more detailed biomechanical information than manual observation. This technology has the potential to improve the quality of swimming learning by providing fast, objective, and data-driven feedback. The implementation of computer vision in swimming learning is also in line with the development of digitalization of sports education which demands the use of innovative technology to increase the effectiveness of the learning process. Thus, the use of computer vision can be one solution to improve the swimming technique competence of students of the Faculty of Sport Science more effectively and measurably.

5. Conclusion

Based on the results of research on detecting freestyle swimming movement mistakes using Computer Vision technology on students of the Faculty of Sport Science, it can be concluded that Computer Vision technology is an effective method for identifying and evaluating swimming technique mistakes objectively, accurately, and consistently. The use of a pose estimation-based system allows movement analysis to be carried out automatically, thereby reducing the subjectivity that often appears in manual assessments by lecturers or coaches.

The results of the study showed that there were still various technical mistakes made by students when practicing freestyle swimming. The most dominant error was unsynchronized arm and leg coordination with a percentage of 32.3%, followed by the head being too high when breathing at 30.7%, unrhythmic leg kicks at 28.3%, too low hip position at 27.0%, excessive head rotation at 26.0%, less than optimal arm pull at 24.7%, and imperfect arm push at 23.0%. These findings indicate that aspects of movement coordination, breathing techniques, and body position are still the main weaknesses that need attention in the freestyle swimming learning process.

In addition to successfully identifying various types of technical mistakes, the Computer Vision system used in this study also demonstrated excellent performance. Test results showed an accuracy of 90.8%, a precision of 89.5%, a recall of 90.1%, and an F1-score of 89.8%. These values indicate the system's high capability in

detecting movement mistakes made by students. Furthermore, the results of the suitability test using the Intraclass Correlation Coefficient (ICC) produced a value of 0.87, which is included in the high reliability category. These results indicate a strong level of agreement between the system's detection results and the assessments of swimming expert.

Overall, this study demonstrates that computer vision technology can be used as a modern, data-driven alternative for evaluating swimming techniques. Implementing this technology has the potential to improve the quality of swimming instruction by providing faster, more objective, and measurable feedback. Therefore, the use of computer vision can support a more effective swimming learning process and be part of the digital transformation of sports education in higher education.

Lecturers and coaches are advised to utilize computer vision technology to support swimming learning evaluations to improve the objectivity of assessments and the quality of feedback to students. Further research can develop real-time analysis systems, expand observations to other swimming styles, and integrate more complex biomechanical parameters to improve the accuracy and effectiveness of technology-based swimming learning.

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Author Declaration

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