UNIVERSITAT DE GIRONA

Final report laboratory:

“THE NEURAL DETECTIVE”

Solving the U-Net mystery

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e-Health MAIA

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1. Introduction

In the realm of biomedical image processing, medical image segmentation is an essential and critical step in the field of biomedical image processing [1]. How to automatically recognize and segment the lesions in medical images has become one of the issues that concern lots of researchers. Conducting manual segmentation means a heavy workload for doctors [2]. To address this challenge, Ronneberger et al [3] proposed U-Net at the MICCAI conference in 2015, which was a breakthrough of deep learning in the segmentation of medical imaging. U-Net is a Fully Convolutional Network (FCN) applied to biomedical image segmentation, which is composed of the encoder, the bottleneck module, and the decoder. The encoder systematically extracts hierarchical features, utilizing convolutional and pooling layers. At the core, the bottleneck module strategically condenses and encapsulates vital information crucial for accurate segmentation. In the final stage, the decoder reconstructs spatial details, generating a comprehensive segmentation map from the condensed information obtained through the encoder and bottleneck module.

In our lab, we've introduced an engaging and interactive approach to familiarize our classmates with the parts of U-Net. The main theme revolves around a game where participants take on the role of detectives tasked with solving a mystery. Groups of six detectives investigate the cause of poor segmentation results for Dr. Luna, a brilliant data scientist, which could lead to funding cuts. Each member explores the U-Net architecture, pinpointing the components responsible. This hands-on approach not only enhances understanding but also highlights the real-world impact of addressing segmentation challenges in medical imaging.

This report presents all the steps taken to develop the final idea and gather the final feedback from the participants.

2. Brainstorming and idea construction

In the first meeting, ideas were proposed about the topic to be taught and the dynamics to be followed. Some of the proposed topics were:

- Global Concepts of Deep Learning and Image Processing
- Knowledge of Pathological Imaging
- U-Net architecture

After having discussed the pros and cons of each topic, it was decided that “U-Net architecture” was the most appropriate topic since in the field of medical images, the U-Net architecture is currently widely used for image segmentation, and understanding its structure and operation is essential.

After deciding the topic another brainstorming was made to choose the dynamics to follow, some of the proposed dynamics were:

1. Buzzer quiz:
   The dynamic was based on a buzzer quiz game, where groups of participants would compete to answer questions related to U-Net architecture. Before each question, an explanation or a hint would be given.

2. MAIA U-Net:
   The plan was to provide stories involving MAIA students and their professors, illustrating the primary function of specific deep learning components such as the Loss function, optimizer, learning rate, accuracy, encoder, skip connection, decoder, etc. The objective of these stories is to encourage students to analyze the individuals in the provided stories based on their functionality and match them to their corresponding deep-learning components.

3. Solve the U-Net mystery:
   The idea was to create a game akin to a "Murder Mystery". The plan was to weave a central mystery, enriched with clues and characters, into a storyline. This setup was not just for entertainment; it was also designed to impart knowledge about Deep Learning, specifically the U-Net architecture. The concept was to use the unfolding story to guide participants through the intricacies of U-Net, making the learning process interactive and intriguing.

As with the decision on the topic, the pros and cons of each dynamic were discussed and it was decided “Solve the U-Net mystery" as the main dynamic, but with the integration of some aspects of the other propositions.

3. First Feedback (Before laboratory execution)

After presenting the idea to our classmates and teachers, we receive feedback from them. The majority were interested in seeing an interactive and enthusiastic activity, others were concerned about how the activity would be implemented.

Here are some of the feedback taken into consideration:

“It seems a really fun idea for the lecture! Perhaps, to make the lecture more interactive, besides the quiz questions we could have additional games or challenges where groups could compete for points (ex: crossword puzzle / Wheel of Fortune / Lingo style games but using relevant words from our master).”

“The idea is exciting, and I am looking forward to it. My primary concern is balancing the game and ensuring that players have access to all the clues during the activity. “

“I like the idea. It is interesting and challenging Maybe you can add some hints or information for each choice like a characteristic to consider.”

Taking into account the provided feedback and discussing again the main idea, tow may Challenges arose:

1. To craft an engaging dynamic: To solve this challenge, inspiration from the game "Chinese Whispers," was taken, the game is recognized for its simplicity and the entertaining distortion of messages during transmission, so the potential to adapt this game to elucidate the fundamental functionality of U-Nets was observed. The concept revolved around integrating a mystery-solving element, enabling participants to grasp U-Net concepts through an engaging activity. Exploring ways to enhance enjoyment and engagement, the consideration of incorporating drawing into this dynamic was contemplated.

2. The strategy to deliver each challenge: To solve this challenge, the decision was made that no electronic material would be used (except for the pptx presentation) throughout the development of the dynamics. So all the materials that the participants would use would be sheets of paper and colored pencils made available. In this way, it was sure that participants had immediate access to the needed material.

Following those decisions, the next meetings were based on choosing the mysteries (challenges) to be solved.

4. Design and implementation of the chosen idea

The dynamic is based on a game where the participants take on the role of detectives and investigate why Dr. Luna's U-Net, a brilliant computer scientist, is giving such bad results in a semantic segmentation problem.

Participants had to be divided into groups of at least 6 people and work together to solve the mystery. A series of challenges will be proposed in which detectives will train and find clues that will help them solve the mystery.

The proposed challenges are the following:

1. U-Net puzzle:
   Each group will be given a puzzle with the main parts of a U-Net to complete.

2. Detective Training:
   At the end of the puzzle, each participant in the group must select a piece of the network to learn how it works in order to investigate it thoroughly. The possible parts to choose from are encoders, bottleneck decoders, and skipping connections.

3. Segmentation challenge:
   With the knowledge gained during the training, the participants of the group will form a U-Net and have to segment an image. Each group will be given an input image and other materials (clues) to be able to perform the segmentation.

4. Solve the mystery:
   Once the groups have done the segmentation, they will be given the ground truth, and together with all the found hints they have to find out what is the problem of the network.

In the end, some groups may discover that the mystery was that Dr. Luna's ground truth was corrupted and therefore the network did not perform well.

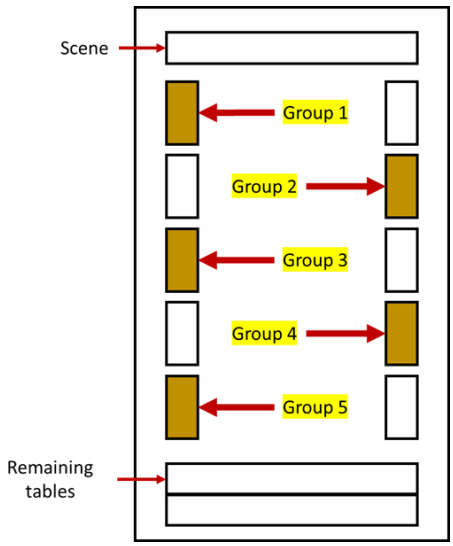
5. Laboratory preparation

Once the main aspects of the dynamics had been established, it was proceeded to establish all the necessary details for the proper development of the lab and the challenges. In the following section, each stage of the dynamic will be explained such as the organization of the groups (number of people and location in the classroom), the materials needed, the person in charge of directing it, and the maximum time to perform it.

1. Organization of tables and groups

Duration: 3 min max
Managers: Agustin, Hisham

Before starting, the tables have to be arranged as in the image and the participants should form groups of 6 people. If people are remaining, they have to be distributed in the groups. Each group must be positioned at the tables indicated in yellow.



2. Presentation

Duration: 5 min max
Manager: Jaqueline

Introduction of the dynamics

1. Explain the objective of the global dynamics: Teaching the structure and functioning of the U-Net

2. Explain the theme of the global dynamic: Solve the mystery that will cause Dr. Luna to lose funding for his research. Participants must take on the role of detectives and thoroughly investigate the network to see what is causing the bad results.

3. Puzzle

Duration: 7 min max
Manager: Jaqueline

Preparation of the dynamics:

Distribute an answer sheet and the pieces of the puzzle to each group.

Purpose of the dynamic:

The goal of the dynamic is to familiarize detectives with the parts that make up a U-Net.

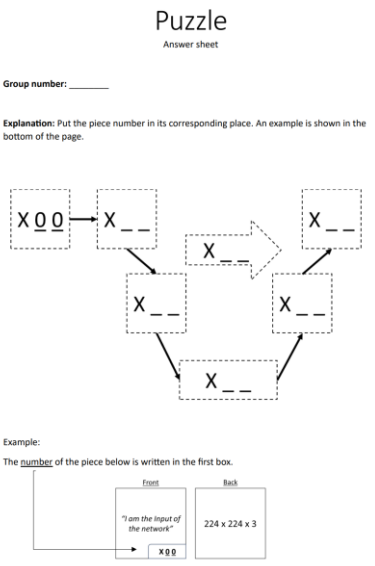
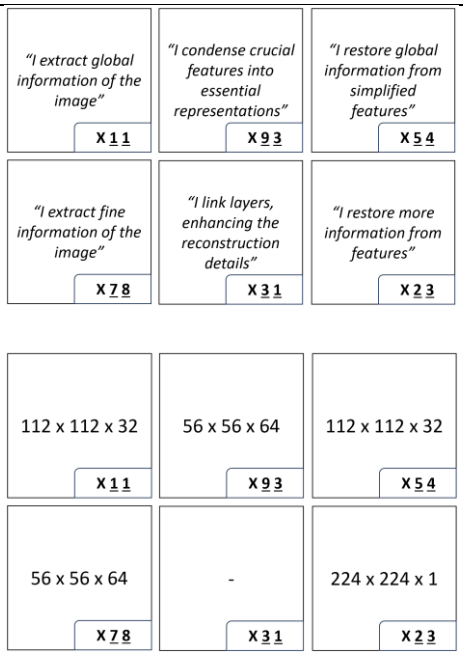
Explanation of the dynamics:

Each team has 6 pieces of a puzzle that they must organize. Each piece contains, on one side, the explanation of the part, and on the other side, the size of the output. On both sides, it will also be found the piece number. That number is the one they must write in the answer sheet in the matching space that the piece goes.

Dynamic Correction:

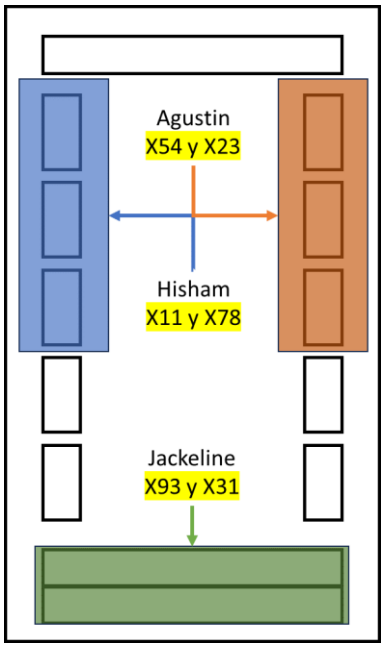
Finally, the correction will be displayed (no evaluation of results will be made)

Materials:

Answer sheet	Pieces
	

4. Detectives Training

Duration: 14 min max
Manager: Agustin, Jaqueline, Hisham



Preparation of the dynamics

At the end of the previous dynamic, the members of the group will be asked to choose a piece of the puzzle. If there are more than 6 people in the group, 2 people should take the piece with the code X93 (Bottleneck).

- Those with the pieces code X11 and X78 (encoders) should go with Hisham
- Those with the parts code X93 and X31 (BN/SK) should go with Jaqueline
- Those with the pieces code X54 and X23 (decoders) should go with Agustin

Players must move to the place indicated in the image:

Purpose of the dynamic:

The dynamic aims to train detectives to know how decoders, encoders, bottleneck, and skipping connections, work.

Encoder Explanation

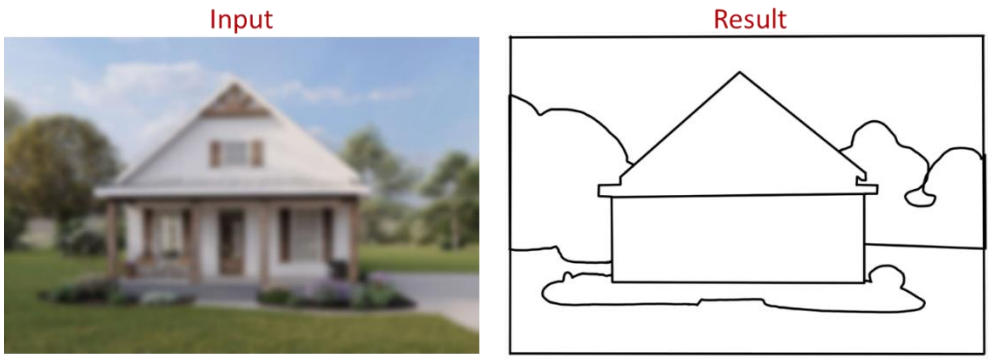
Manager: Hisham

- Teaching:

  Participants will learn how the encoder part works. In each group, there must be at least 2 encoders.

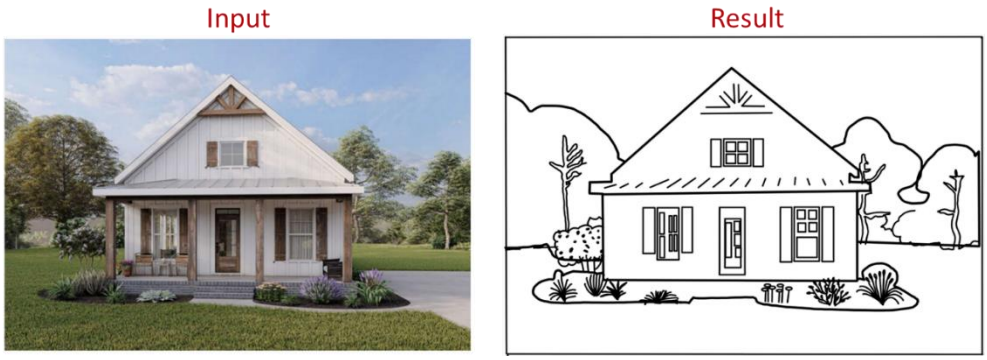
  <u>Low-resolution encoders:</u>

  The second encoder (those with the X78 code) will learn to extract general characteristics from an image. They should focus on general aspects and overall shapes, such as the silhouette of objects, general distribution of colors, and large blocks of textures. The input for these participants is going to be the low-resolution image and the output is going to be global outlines of the image as seen below.



High-resolution encoders:

The first encoder (those with the X11 code) will learn to extract fine features from an image. They should focus on fine details and high-resolution textures, such as small color variations, precise edges, and detailed patterns. The input for these participants will be the original high-resolution image. These encoders are going to draw fine details over the result of the second encoder and the output should be the image with more detail.



- Training:

  After the encoders have learned what they must draw from the images. They can proceed to do a little training.

  - A low-resolution image will be available to the second encoders (X78) and they must extract global characteristics from the image
  - Then A high-resolution image will be available to the first encoders (X11) and they must complete the drawing of the second encoder extracting more fine features from the image.

  At the end of the training, the encoders will be shown the result they should have obtained.

BottleNeck / Skipping connections explanation.

Manager: Jaqueline

- Teaching

  Participants will learn how the bottleneck part and the skipping connections work.

  Bottleneck:

  Bottlenecks (those with the X93 code) will learn how to extract relevant features from encoder results. To do this, they will have a form with objects that may appear in the image. An example of the result of the encoders and which forms should be selected will be displayed.

Encoders result

Form to fill

Skipping connections:
Skipping connections (those with the X31 code) transfer contextual and detailed spatial information from the encoder results directly to the decoders. This helps preserve location details that might be lost in the bottleneck form.
While the decoders recreate the image with the information from the forms, the skipping connections must help them.

They have to tell them: In what position of the image, What size, and the relation of the objects of the bottleneck form. The skipping connections can go to the bottleneck table, look at the result of the encoders, and come back to help the decoders as many times as they want. Skipping connections should neither draw nor add things to the form.

- Training

  Bottleneck:
  After learning how to fill out the form, the bottlenecks will be given a possible result of the encoders and a form to fill out. At the end of the training, the bottlenecks will be shown a form filled out with the things they should have selected.

  SkippingConnection:
  There's no training for them, they just have to learn to transfer information.

Decoder Explanation

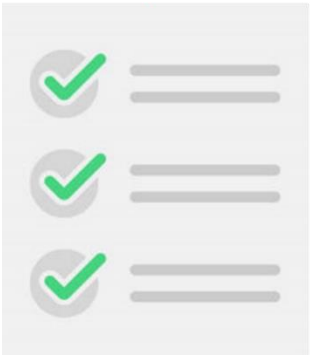
Manager: Agustin

- Teaching:

  Participants will learn how the decoder part works. In each group there must be at least 2 encoders.

  Low-resolution decoders:
  The first decoders (those with the X54 code) will learn how to reconstruct the image from abstract features. The input for these participants will be the bottleneck form plus the help that the skipping connection can provide. The result should be a draft that contains the edges of the objects.

Input



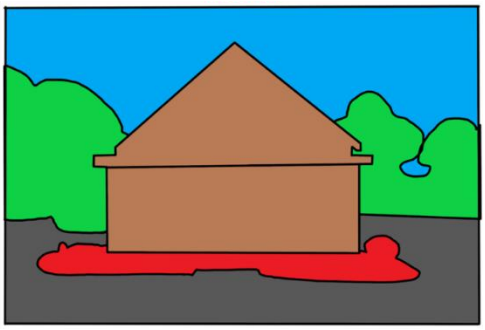
Result

High resolution decoders:

The second decoders (those with the X23 code) will learn how to label the images. They must learn to unify elements belonging to the same class and give them the same label. The input for these participants will be the number of labels, the draft of the first encoder, and the help that the skipping connection can provide. They are going to draw on the draft of the first encoder and the result should be the image labeled with colors.

Input

Result



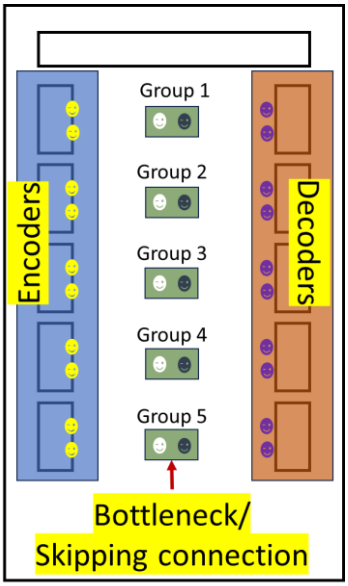
- Training

  After learning how to reconstruct the image and label it, the participants will be trained:

  - An example form with possible information filled in by the bottleneck will be given to the first decoders, they should try to recreate the image with as much detail as possible.
  - Then the results of the first decoders will be passed to the second decoders and the number of labels will be given so that they can proceed to label the images.

  At the end of the training, the decoders will be shown the result they should have obtained (labeled image).

5. Segmentation Challenge



Duration: 12 min max
Manager: Agustin

Preparation of the dynamics:

Place each team in its position: Encoders on the left side. Bottlenecks and skipping connections in the middle and decoders on the right side.

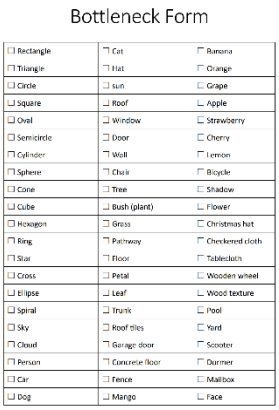
Purpose of the dynamic:

The goal of the dynamic is to label an image.

Explanation of the dynamics:

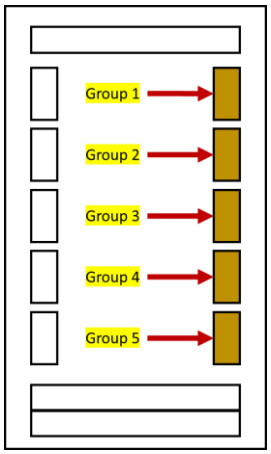
Each group is going to label the image that will be given to them. Each part of the network will work as explained during the training. The first to work with will be the encoders. Then the bottleneck and finally the decoders with the help of the skipping connection. The result must be the labeled image.

Materials:

Input image High-resolution	Input image Low resolution	Bottleneck form
		

6. Solve the mystery

Duration: 4 min max
Manager: Agustin



Preparation of the dynamics:

Each group must be positioned at the tables indicated in yellow as at the beginning. The teams must take all their evidence (original images, forms, encoder results, and of course segmentation). The corrupted ground truth (GT) will be distributed to each group.

Explain the purpose of the dynamic:

The goal of the dynamic is to discover the cause of the poor results of Dr. Luna's U-Net

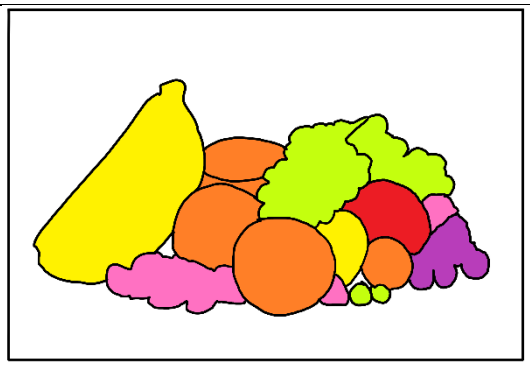
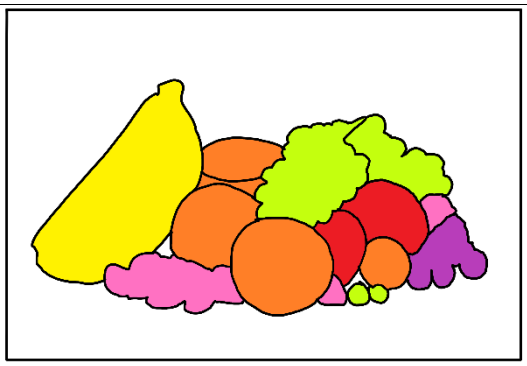
Explanation of the dynamics:

With all the evidence and the real labelling, the detectives must find out what may be the cause of Dr. Luna's poor results. They should see one of the possible results in the form. Each team will have 2 minutes to give a final verdict.

Dynamic Correction:

Finally, the real reason for Dr. Luna's poor results will be shown (the not corrupted ground truth), and the team that got it right will be the winner.

Materials:

Corrupted GT	**Not Corrupted GT**
	

6. Laboratory Execution

Once the concept and learning objectives were established, a team meeting was held to consolidate and visualize the ideas in action. Tasks were assigned for the procurement of necessary materials to execute the activity. During this phase, a technique termed "minute-by-minute" planning was employed. This meticulous approach involved detailing every event and action within a 45-minute duration, guaranteeing both time-realism for planned activities and comprehensive material preparation. This method facilitated efficient organization and preparation for the successful execution of the activity.

Time (min)	Activity	Details	Input	Output
00-03	Presentation - Dynamic introduction	Introduction of the activity to the participants	1.PPT 2.Room layout	1.Teams organized
03-10	Puzzle	First challenge. Matching U-Net architecture.	1. Teams organized 2. Puzzle template 3. Puzzle pieces 4. Pack of colors for every team	1. Puzzle answered 2. Every member of all teams with a role assigned
10-24	Detectives Training	Training session for the participants to learn the detective skills needed.	1.Members with role assigned going with their hosts 2. Material to train per role (Decoder, Bottleneck and Encoder)	1. Members trained 2. Every role in their assigned position in the room
24-36	Segmentation Challenge	Second challenge is split into three parts: Encoder, Bottleneck, and Decoders.	1. Drawings assigned for encoders 2. List of features for bottleneck 3. Images for decoders	1. Reconstruction of the image with a drawing (encoders) 2. List of features describing the image (bottleneck) 3. Final segmentation
36-41	Solve the mystery	Final activity where participants match all the clues, they received to solve the mystery	1. Final segmentation per team 2. Mask for the given image	1. Conclusion and solution of the mystery per team
41-45	Closure	Reflexion about the importance of data quality.	1. Conclusion of the mystery solution per team	1. Reveling answer and making a reflection about data quality

The utilization of detailed planning significantly contributed to the visualization and preparation for the execution day, ensuring readiness for every team member to manage dynamics in case of incidents. However, an unforeseen challenge arose. On the laboratory day, the anticipated flat room for our activities was replaced by a sloped auditorium, contrary to our expectations for such labs. This situation posed difficulties since our dynamics required a "U" shape setup to effectively introduce the concept of U-Nets. Nevertheless, a plan was devised before commencing the lab session. Consequently, a swift proposal and implementation of a solution were executed by the team to adapt to these unexpected circumstances. This experience highlighted the significance of flexibility and adept problem-solving when faced with logistical challenges.

7. Second feedback (After laboratory execution)

Future Enhancements and Recommendations:

Following the conclusion of the laboratory session, the focus was shifted towards assessing the participants' reception of the session. A questionnaire was formulated and distributed to collect feedback regarding participant satisfaction and acquired knowledge. The survey encompassed four primary inquiries, each tailored to capture distinct aspects of the attendees' experience and the knowledge assimilated during the session. The inquiries can be summarized as follows:

1. Strengths Noted:

- The lab was interactive and engaging, making the U-Net theory easier to understand through practical application.
- The team managed the lab smoothly and on time.
- The use of group activities was appreciated for its creativity and organization.
- The lab was well structured, conveying practical knowledge of U-Net architecture effectively.

2. Areas for Improvement:

- Venue Preparedness: Future planning should include confirming the venue in advance to ensure suitability for the activities planned. This could prevent issues like the challenge faced with the sloped auditorium.
- Clearer Communication: Enhancing communication, especially regarding theoretical aspects and activity instructions, could prevent confusion and miscommunication.
- Time Management: Some feedback indicated a need for more time for activities or a clearer understanding from the start.

3. Additional Suggestions:

- Providing printed instructions to each group member before the session could help manage the session in any scenario.
- Improving overall communication, possibly affected by the classroom layout, would enhance the experience.
- Maintaining group engagement is crucial. The positive response to the video shown in a previous lecture suggests multimedia elements are effective.

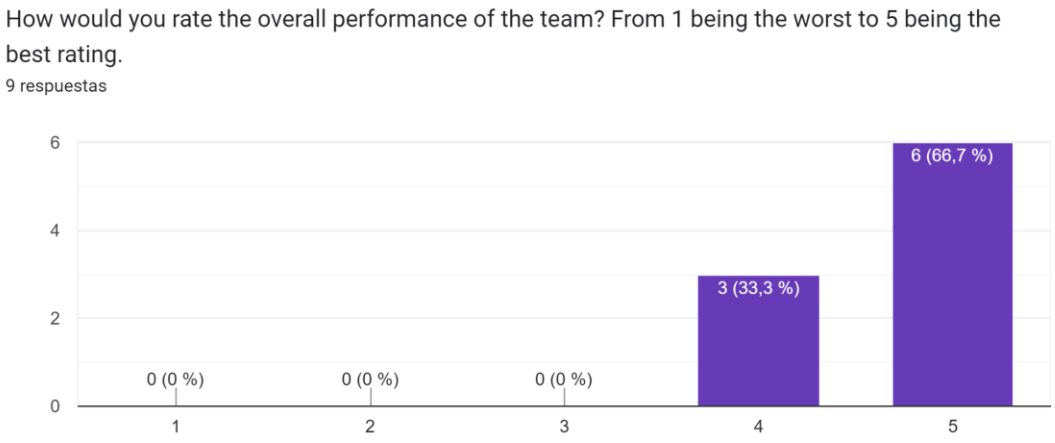
4. Satisfaction surveys:

Reflecting on the satisfaction surveys collected from the participants of the lab, the hard data presents a compelling narrative of our team's performance and the effectiveness of the activity.

For the overall performance of the team:

- 6 respondents, accounting for 66.7%, gave us the highest rating of 5.
- 3 respondents, making up 33.3%, rated us with a 4.

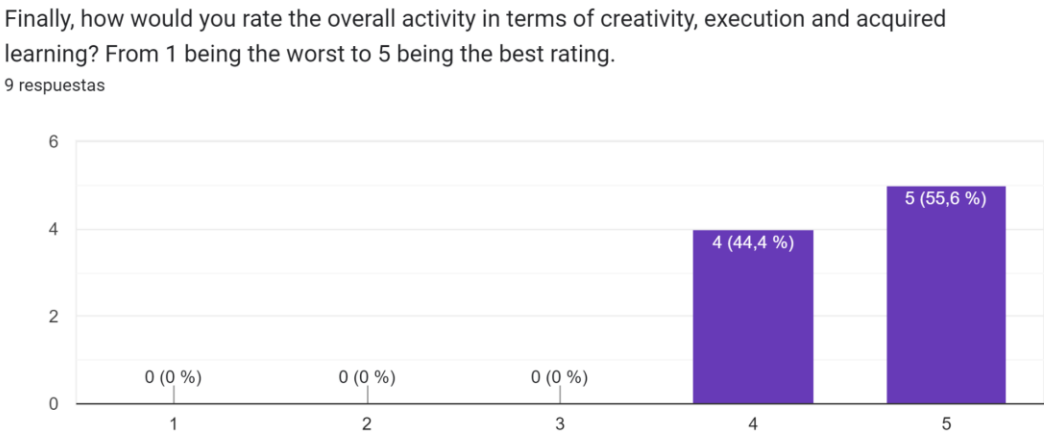
Impressively, there were no ratings below 4, indicating a strong positive reception of our team's efforts.



Regarding the overall activity in terms of creativity, execution, and acquired learning:

- 5 respondents, which is 55.6%, felt that we deserved the top rating of 5.
- 4 respondents, or 44.4%, gave us a 4.

Again, there were no ratings below 4, underscoring the success and positive impact of the activity.



These ratings reflect a high level of satisfaction among the participants, with a unanimous agreement that the performance was well above average. The absence of lower ratings suggests that the activity resonated well with the attendees, both in terms of its delivery and its educational value.

The quantitative feedback obtained validates the innovative approach implemented and corroborates the qualitative feedback emphasizing the interactive nature of the activity and the team's efficient management. Looking ahead, pride can be taken in the accomplishments while also considering constructive feedback as a means to refine and enhance future labs. Overall, the student lab represented a pioneering and engaging method for teaching U-Net concepts. The meticulous planning and the team's adaptability, particularly in addressing the unexpected venue challenge, emerged as notable strengths. The interactive nature of the lab and its structured content effectively facilitated a deeper comprehension of the subject matter. Nonetheless, there remains room for improvement in venue readiness, clarity in communication, and organizational structure for subsequent iterations. This experience has underscored the significance of preparedness for diverse scenarios and the value of effective communication within educational contexts. The team's performance stands as a testament to its strong capacity for innovation and adaptability within an educational framework.

8. Conclusions

In summary, the student lab presented an innovative and captivating approach that brought the theoretical underpinnings of U-Nets to life through interactive and participatory means. The strengths observed included meticulous planning and the team's adeptness in adapting to an unforeseen venue challenge, emphasizing the importance of readiness for diverse situations. The structured content and interactive elements of the lab facilitated a comprehensive comprehension of the material and promoted collaboration among peers. This facilitated a collective understanding of U-Net's fundamental components like the Encoder, Decoder, Bottleneck, and Skip Connection, highlighting the significance of segmentation and data quality. While opportunities exist for improvement in venue readiness, communication clarity,

and organizational structure, the team's performance and innovation are sources of pride. This experience has emphasized the value of effective communication and adaptability within educational contexts, ensuring the delivery of a comprehensive and enlightening learning experience. Going forward, these lessons will guide our efforts in refining methodologies for enhanced educational pursuits.

9. References

[1] G. Litjens, T. Kooi, B. E. Bejnordi, A. A. A. Setio, F. Ciompi, M. Ghafoorian, J. A. van der Laak, B. van Ginneken, C. I. Sánchez, A survey on deep learning in medical image analysis, Medical Image Analysis 42 (2017) 60–88. doi:https://doi.org/10.1016/j. media.2017.07.005.
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