Incorporating a Reusable Human Robot Interface with an Auction Behavior-Based Robotic Architecture

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ABSTRACT- Service robots have the potential of improving the quality of life and assist with people's daily activities. Such robots must be capable of performing multiple tasks and schedule them appropriately while interacting with people over long periods of time. In addition, the robots have to deal with potentially unknown users, handle requests that may have (critical) time constraints and perform in dynamic environments while effectively addressing all the requests received. This paper demonstrates the use of the Auction Behavior-Based Robotic Architecture (ABBRA) in order to develop effective service robots. The proposed approach has the following contributions: i) it enables long-term autonomy and interaction with known and unknown users, ii) it handles multiple user requests while dealing with potentially critical time constraints, iii) it provides a reusable interface based on ABBRA, which can run on multiple platforms and iv) it supports flexible interactive capabilities such as requesting that the user wait in order to complete a time sensitive task. The proposed system was validated on two physical robotic platforms: the Adept Mobile's Pioneer 3Dx ™ and the Segway RMP®.

I. INTRODUCTION

While robotic technologies have greatly advanced in recent years, wide spread deployment of service robots has still not been achieved. Given the complexity of robotic challenges, a lot of research is focused developing robots that perform a single task very well. Such robots simply shutdown after the task is complete and their tasks often have limited interaction with humans, as robots usually view the humans as obstacles more than opportunities for interaction. However, service robots need to posses long-term autonomy and continuously be prepared for human interaction, even when they have finished the assigned tasks in order to receive new tasks. In addition, service robots must also remain alert for human interaction while performing an assigned task. This means the robots must interact with multiple, different people for a prolonged period of time while still keeping a high level of performance.

This paper presents several contributions. By integrating ABBRA within a Human-Robot Interaction (HRI) framework, it allows for long term autonomy and interaction with known and unknown users. The robot can receive and handle multiple user requests and, using ABBRA, will handle them in the most efficient manner. If there are any time constraints on the requests, ABBRA allows the robot to handle them appropriately. In addition, the auction-based robotic architecture is integrated with a reusable HRI interface. The components for the interface were chosen based on the control architecture and can run on multiple robotic platforms demonstrating the reusability of the interface. The system also provides for flexible interactive capabilities: if the robot is engaged in a time critical task, the robot requests a new user to wait until the task is handled. Along with this contribution, the robot can deal with a user that is not interacting with it correctly. Two robotic platforms were used to validate the system: Adept Mobile's Pioneer 3Dx ™ and the Segway RMP®.

This paper is divided into the following sections: Section II provides the motivation and general approach, section III gives the related works, section IV provides the Design and Methodology, section V presents the results from the test, and section VI section concludes the paper.

II. MOTIVATION AND RELATED WORK

Currently, approaches to HRI can be broadly broken down into two different schools of thought: task-centric [1] and human-centric [2] design. Task-centric HRI typically design robots to interact in the context of a specialized application such as search and rescue [3-6], specialized interfaces or tele-operation [7]. This school of thought often considers various scenarios for robotic applications [16, 17] and deals with the application requirements for task completion when designing the HRI modules. This can result in specialized systems where the interaction is unique to the situation. Examples include space exploration [18] and search and rescue applications [3-6]. It is also important to mention that for specific applications a teleo-operated system is more appropriate [7]. Application-centric design pursues new interfaces for humans and robots to interact in order to improve the performance of the robotic system for the specific application. These novel interfaces include haptic devices [19], novel environmental indicators [20], gesture recognition [21, 22], tangible interaction [23], and vocal interaction [24, 25]. Because this area focuses on novel interaction, very little focus is given to the reusability of the human robot interface.

The application-centric design method is often based on a specific application or research initiative and result in a specialized approach to human-robot interaction. This means that once the robot is started, it will perform a certain task until completion and then turn off. This does not allow for a prolonged period where humans can interact with the robot and when it does, often only people with a high level of training can accomplish it. This design philosophy often considers high performance better than the ease of interacting with the robot. Therefore, a steep learning curve can accompany an interface designed from application requirements.

The second broad area of HRI consists of socially aware or emotional robotics. This field could be classified as a specialized interface, but the design behind these interfaces has a subtle difference. This philosophy designs the interface from a human-centric perspective [2]. This philosophy takes into account the needs of the human user before considering the application or performance of the system, instead this area of research focuses on what kind of users will be interacting with the system [26] and what emotional needs are required. Similar to application-centric design, this philosophy also leads to specialized applications. However, these applications deal mainly with the targeted users instead of completion of a certain task. For example, robotic therapy has become an emerging field in robotics. Originally, care providing robotics was limited to aiding the elderly and disabled [27]. However, now robots can provide care and therapy for autistic children [28], rehabilitation patients [10], and even provide an element of psychological care [9]. Another relevant field is robotic pets [8] where researchers observe the affects of children playing with robotic animals versus their biological counter-part. Another major application of this design philosophy is how robots react to human emotions [29-31] and how humans emotionally react to robots [32-36]. The primary focus of this research is to promote emotional, social and psychological acceptance of robots in society.

The CoBot research project is most similar to our work [37], with a major focus on planning and navigation for indoor service robots. The CoBot robot uses a collaborative control schema, with which the robot requests help from the user if it detects that it cannot complete the desired goal [38, 39]. ABBRA uses an auction behavior-based system for dynamic task allocation for individual robots. This allows the robot to determine which task is most important to run at that moment based on several constraints, including the possibility of accepting or denying an interaction with a human based on its current time constraints. This is in contrast with the approach used by CoBot, whose scheduling algorithm creates a conflict-free plan, which frees the robot from dealing with interruptions from users [40]. Furthermore, CoBot does not deal with direct interaction with people, but instead follows a schedule that was generated from requests coming from the web. This work was also extended to explore interesting research regarding robotic teamwork and planning [41]. In one approach [42] robots provide tours and decide who should do what in their tour based on previous knowledge. However, robots are not designed to handle un-cooperative users or direct interaction with people, apart from following the robot on the tour. In contrast, the work described in this paper deals with direct and sometime unexpected interaction with human users.

Several existing approaches mention of the need for reusability in HRI interfaces [43]. However, these papers focus on reusability in one of two methods: either they refer to the need of reusing either the robotic architecture [44, 45] or the component of an HRI interface [46]. Both of these philosophies are good, however, in these cases reusability not the main concern of the work

III. APPROACH

The research in this paper approaches this problem neither from the robotic application nor a human-centric design but rather from the control architecture of the robot itself. The Auction Behavior-Based Robotic Architecture (ABBRA) has already demonstrated that it can provide a robust action selection mechanism for service robots [11-13].

ABBRA will allow behaviors to compete for control of an actuator. This is accomplished by each behavior collecting metrics from the environment and submitting to an auction. Each behavior is assigned an activation level based on the metrics it submitted. The auction cycle is continually bidding therefore allowing ABBRA to handle changes and noise in the environment and handle new jobs being added during runtime. The robot can also handle task with time constraints and determine if a task has enough time to finish and how important the behavior is to run at that moment. ABBRA is designed to be independent of specific applications instead; it is designed to arbitrate between sets of generic behaviors. This makes ABBRA an ideal base to design a generic interface. For more information, see other articles on the architecture itself [11-13].

ABBRA is designed to run on a generic robot platform, with no particular need for specific hardware. With this design feature coupled with the hardware, abstraction provided by the Robotic Operating System (ROS) [14] allows ABBRA to run on multiple platforms. Since the robotic control architecture is a common factor between robots it is an ideal place to start designing a reusable HRI interface. Instead of defining specialized tasks or a set of social awareness requirements, the building blocks used to create the interface were derived from the basic components of ABBRA. After these components were defined, a more human-centric presentation was considered. This allowed the interface to be designed with the same generalities that were built into ABBRA and the capability of running on different robotic platforms.

Along with reusability, time constraints achievement was a concern with ABBRA. The interaction with users is handled as a process identical to those used for executing service tasks. Since the architecture dynamically determines which process to run, if critical time constraints exist, the robot may not choose the human interaction request as the highest priority. By allowing the robot to make decisions, it can take advantage of a cooperating human user and finish time critical tasks before interacting with him/her. Unfortunately, this means the robot must deal with non-cooperating users [15] or a user that does not interact with the robot appropriately. Should the robot encounter a non-cooperating user it will attempt to avoid the person but stop if it cannot avoid a collision.

In this research there are several assumptions made. First, is that in order to implement a reusable interface, all potential robotic platforms using the proposed approach should be running ABBRA as control architecture for the robots. Second, the robot in the proposed system is autonomous except for the times when the user is requesting tasks or information. Therefore, once the user makes his/her selection the robot will continue without the need of human intervention. Third, is that the user is not interested in raw data (sensory or motor control). In some robotic applications, such as space exploration, the user will be interested in every piece of data collected. However, for service robots it is more likely that the user is more interested in having the robot complete tasks than analyzing raw data. Although issues regarding emotional and socially aware robotics have significant importance in HRI, this paper will focus more on the practical approach in which the user is not as interested in connecting emotionally to the robot, but rather in getting the robot to complete a desired task. However, several socially aware concepts were used in the interface to aid the robot in better communicating to the user. No assumption is made regarding the cooperation of the user, except for common sense when dealing with machinery.

IV. DESIGN AND METHODOLOGY

Scalability, portability and pre-existing understanding by the public were the three reasons why a Graphical User Interface (GUI) was chosen as the interface to interact with ABBRA. GUIs provides widgets or controls that the human user will interact with either through a mouse, touch screen or some other 2D input device. Should the architecture require a special component most GUI libraries allow for creation of custom widgets. This means that whatever interface needs arise, a GUI will most likely be capable of meeting its needs. The PyQt library was chosen to create the GUI because it ran on python, as does ABBRA, and it can be used on both Windows and Linux platforms. This allows a portability that is not true with all GUI technology. In addition, most mobile devices can run stripped down versions of Linux, which means a GUI that can run under Linux can run on most tablets and even a few smart phones. The research presented in this paper dealt only with physical interaction with the robot, but for future work, remote and mobile interaction with the robot could be explored.

The interface was designed to be functional across multiple robotic platforms with multiple robotic tasks. The underlying ability for this to occur is the common control architecture ABBRA. This architecture, via ROS, can run on a wide variety of robotic platforms. Since reusability was a high priority, primary components of the architecture were used as the building blocks for the GUI. ABBRA has three main components to address the following functionality: the addition of new tasks, the competition of currently running tasks, and the collection of the overall system status. With these components, the interface designed from the architecture is broken down into three parts each representing a component of the architecture.

The interface is divided into three parts: input, status, and facial expression. The input portion of the interface is only displayed when the user requests an interaction by looking directly at the camera. If a person is in front of the camera, the robot will detect the face (using Haar Feature-based Cascade Classifier for Object Detection in OpenCV [47]) and know that a user is requesting to interact with it. The face detection must have a bounding box that is larger than a threshold, in order to stop the robot from detecting every face in the distance. This simple method for starting the interaction provides a proof of concept that the interface can be used by different people.

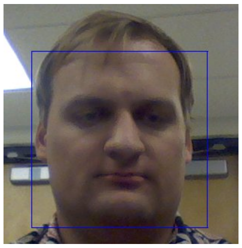
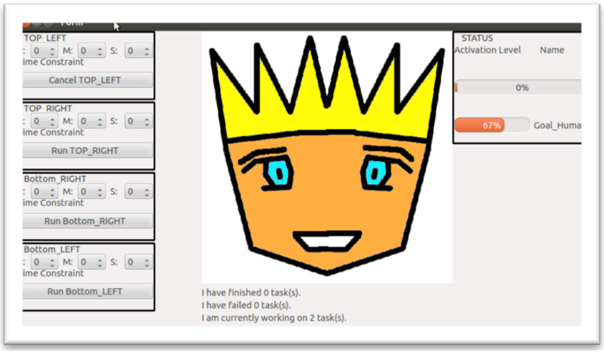


Figure 1: The face detector tells the robot the user wishes to interact.

When the robot detects a face and determines it has time to interact with the user the GUI will display all tasks capable of being performed by the robot on the left side of the screen and allow the user to either run or cancel the task depending on its status.

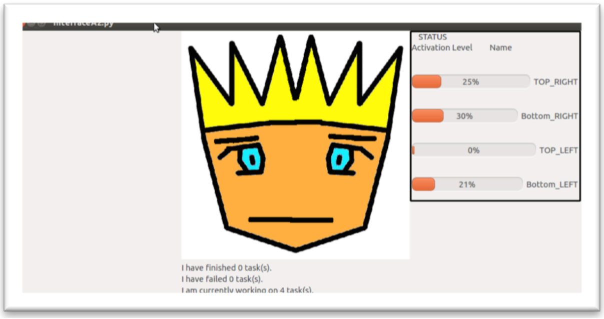


I have finished 0 task(s).
I have failed 0 task(s).
I am currently working on 2 task(s).

Figure 2: Interface in interactive mode

Each task has its own screen area and provides three drop down menus along with a button to run the tasks. If the task is currently running, the button will be used for cancellation of the task. The three drop down menus allows the user to select a time constraint for the tasks they wish the robot to run. The need for a time constraint was also derived from ABBRA, allowing every potential task to have a time constraint. Eventually, this interface could be run on a smart phone or tablet (using a text box can cumbersome for these devices), thus drop down menus were used to input the time constraints. After a task is requested by the user, the label on the button for that task will change signifying press if the user wants to cancel the task. This gives the user complete control of invoking and cancelling tasks that the architecture allows. Ideally, a configuration file for each specific task could be used for the creation of custom parameters besides time constraints. However, for the purposes of this paper only the time constraint was used as a user input parameter.

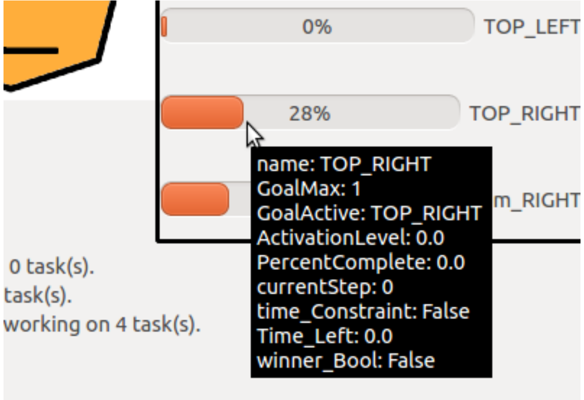
The primary metric for ABBRA is a behavior's activation level, which is used to determine which tasks should control a specific actuator. This metric is displayed as a status bar with the appropriate task name next to it on the right side of the screen. This displays what the priority of the tasks should be from the robots perspective. By displaying the activation level as a status bar, the user could automatically know what task the robot thought was most important. The status box would be visible when the robot is moving or when the robot is in an interactive mode. This means the user does not have to be interacting with it to see this information.



I have finished 0 task(s).
I have failed 0 task(s).
I am currently working on 4 task(s).

Figure 3: Non-interactive mode

If the activation level does not provide enough information to the user, the mouse tooltip, text displayed when you leave the mouse over an object, will provide more information about the specific task.



0 task(s).
task(s).
working on 4 task(s).

name: TOP_RIGHT
GoalMax: 1
GoalActive: TOP_RIGHT
ActivationLevel: 0.0
PercentComplete: 0.0
currentStep: 0
time_Constraint: False
Time_Left: 0.0
winner_Bool: False

Figure 4: Tooltip providing more detailed information.

This demonstrates that the interface is capable of relaying low-level information if the human user desires it.

The last section of the interface was the facial expression displayed in the middle of the GUI. This consisted of a picture with a facial expression portraying the appropriate facial expression with a message underneath it. Humans can understand facial expressions faster than they can comprehend large amounts of data scrolling on a terminal. Therefore the GUI takes behavior data from the robot's current set of running behaviors and determines what facial expression is more relevant for that data. The goal here is not to introduce emotion into the robotic system for human acceptance, but rather portray status of the system through facial expressions. A large amount of work has already demonstrated that mimicking a face with cartoonish features allows human acceptance because it avoids the "uncanny valley" [48-50].

This is an example of taking a component of the architecture and applying human-centric designs to it.

For the research presented in this paper a simple proof of concept was used for visual feedback from the controller. The robot would use five primary facial expressions representing the overall status of the robot. These facial expressions represented upset, sad, unhappy, normal (straight faced), happy, cheerful.

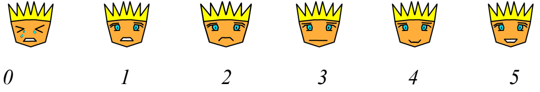


Figure 5: Above from left to right - upset, sad, unhappy, normal (straight faced), happy, cheerful

For proof of concept, simple values taken from the architecture itself were used to calculate the facial expression for the robot. These values included number of active tasks, the number of tasks a robot can have active at once, the number of completed task and the number of failed tasks. The stress and the confidence of the robot were calculated as follows

$$Stress = 1 - \frac{N_{at}}{N_t} \qquad (1)$$

$N_{at} = Numer\ of\ active\ task$

N_t
$= Total\ Number\ of\ tasks\ robot\ can\ do\ at\ once$

$$Confidence = \frac{N_c}{N_c + N_f} \qquad (2)$$

$N_c = \ Number\ of\ completed\ tasks\ by\ the\ robot$

$N_f = Number\ of\ failed\ tasks$

$$E_v = round\left(\left(\frac{Stress + Confidence}{4}\right) * 10\right) \qquad (3)$$

E_v
$= Emotion\ value\ between\ Ineteger\ between\ [0{:}\,5]$

The resulting value would then be mapped directly to the facial expression where 0 corresponds to upset and 5 corresponds to being cheerful. There is one other facial expression used when the robot asks the user to wait while it finishes a tasks, and when the user simply leaves the robot interface and does not interact with it within 45 seconds.

These facial expressions allow the interface to quickly send a message to the human user. Beneath the facial expression is the general message. Most of the time it will display the number of tasks completed, running, and failed. However, should the robot need to ask the user to wait or if another important message occurs, the robot will display the message here.

V. RESULTS

The testing phase consisted of the Pioneer and the Segway RMP robots running through a complex scenario of interactions, goals, and interruptions. These scenarios provided a proof of concept for designing the HRI GUI from the architecture. The facial expression simply allows the user to have an immediate understanding the status of the robot [48-50].

The environment had three objectives with known location that the robot had to reach. These objectives were identified as the yellow, orange and red goal, marked with colored paper in the UNR Computer Science and Engineering building. A fourth objective consisted of finding and investigating a bright green object with an unknown location, which was identified as the green goal. Two users interacted with the robot, one of which is an author of the paper and another an undergraduate student with the Computer Science and Engineering Department. The second user only needed brief instructions on using the interface after which she was able to fully interact with the robot.

The robot used a map of the engineering building on campus. It used the AMCL module from ROS [51] to keep localization and the Move_Base module [52]to plan routes to objectives with known locations.

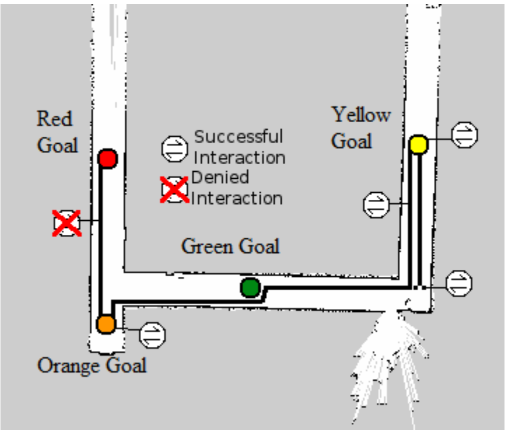


Figure 6: The map of the scenario used to test the HRI module

For the testing scenario, a user initiates testing at the start location (lower right corner in Figure 6) and requests the robot to move to the yellow goal. The robot is allowed to accomplish the goal without interruption. Once the robot achieves the yellow goal, the user then initiates another interaction and requests the robot to move to the orange goal. However, shortly after the robot begins moving, the user attempts to interrupt it. Since the orange goal is not time critical it allows the user to interact with it. This demonstrates that the robot will allow the user to interrupt it when it is not pressed with a time critical task. The user then request the robot find and investigate a green object (green goal). The robot then accomplishes the green and orange goal. The user will then request an interaction with the robot and request it to go to the red goal with a 5-minute time constraint. This time constraint was critical enough to not allow the user to interrupt it. Shortly after the robot starts moving toward the red goal, the user will interrupt it and try to request an interaction. The robot will ask the user to please wait and then avoid the user and continue on to the red goal. This demonstrates that the robot can deny interaction with the user in time critical situations. Once the robot reaches the red goal, the user attempts to interact with the robot but does not assign any new task to the robot. The robot will then time out the interaction, demonstrating that it can deal with users who do not actually want to request a service.

Figure 7: The users with the Pioneer robot and the Segway RMP

The first scenario involved the Pioneer mobile robot. These results demonstrate that the architecture and the HRI interface worked as expected, as the robot appropriately handled the task requests and the interactions with the. The robot received two false positives on the face detection, but the overall interaction went as expected.

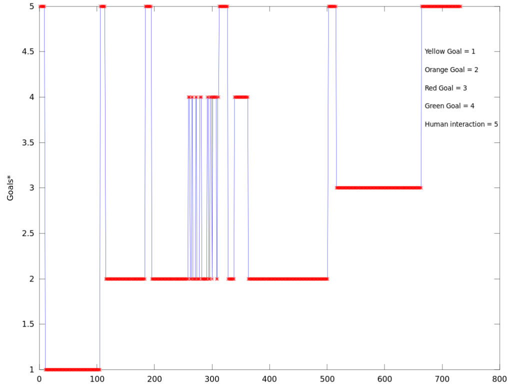


Figure 8: The winning task over time for Pioneer test.

Figure 8 shows the order in which the tasks were handled by the robot (as given by the auction mechanism in ABBRA), including the tasks representing the interaction with the users. When the scenario begins the first task that requests control is the human interaction with the robot. The user requests the robot to go to the yellow goal and allows it to complete the task. The human then requests another interaction and tells the robot to go to the orange goal. The user then interrupts the robot again and requests the task of finding a green goal. Given that the orange goal had a known location, the auction mechanism chooses to pursue the orange goal. However, around time step 260 the robot detects the green target with an unknown location and the control is switched to finding the green goal. After reaching the green target, the robot switches back to going to the orange location. During this time there are two false positives from the face detection module, which did not affect the overall behavior of the robot. There is also some oscillation due to noise from the blob-tracker, which also did not affect the robot's performance. The reason this oscillation did not affect the performance is because ABBRA can handle large amount of noise from the environment and still maintain a high level of performance. This noise in the environment demonstrates that the auction mechanism for behavior selection in ABBRA is also robust to noise in the environment. As a last task, the user requests the red goal with a time constraint. Notice that no human-robot-interaction occurred after this even though it was attempted. After the red goal is finished, the robot is left in an interactive state until it times out and continues its wait for a new request for service.

The second test was run on the Segway RMP and followed the same testing scenario. The robot performed as expected, except for a few false positives with the face detection and some oscillation between the green and orange goals, which were again handled gracefully by the robot's control architecture.

Figure 9 details the winning behaviors over time for the Segway run. In this experiment, similar to the run with the Pioneer, the robot does not allow the user to interrupt the red goal because it has a time constraint.

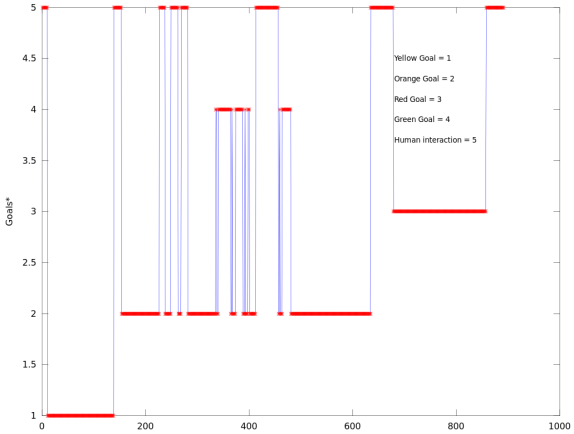


Figure 9: The winning task over time for Segway test.

VI. CONCLUSION

This paper has demonstrated the use of the Auction Behavior-Based Robotic Architecture in developing effective service robots. ABBRA enables long-term autonomy and interaction with users while being integrated with a reusable interface that can run on multiple robot platforms. ABBRA allows robots to handle multiple user requests and provides high quality performance for task selection based on what task is most critical to finish first. This includes requesting the user to wait for a time critical task to finish before interacting. The experimental evaluation also shows that the robot can handle a scenario where the user does not cooperate. The proposed system was validated on two different robotic platforms. The results show the potential of this architecture for developing service robots that can operate over extended periods of time in the presence of people in dynamic environments.

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