Cleaning Up Interactive Cleaning

Final Study Report

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1. Executive Summary

This document presents the final report on the Cleaning Up Interactive Cleaning ALMA Development Study (Cycle 4). This project funded the development of interactive cleaning functionality within the Cube Analysis and Rendering Tool for Astronomy (CARTA), which was previously developed and delivered to NRAO for ongoing development in the CASA group.

The purpose of the project was to provide Interactive Cleaning functionality within the CARTA visualization tool. This functionality allows for the manual control of the deconvolution process for interferometric imaging from within CASA. Interactive Cleaning is currently provided by a modified version of the CASA viewer software, which will be retired on completion of the CARTA project.

The original plan for the project was to developing a GUI in CARTA which then would use the established interprocess communication technologies for controlling cleaning in CASA by other software. The original interprocess communication channel (dbus) is not fully implemented and a new technology will soon be adopted by the CASA group. Further, the CARTA project began and end-to-end re-architecture of the project, making it difficult to contribute to during this redesign. As such, we were not able to meet our original deliverables. Working with the CASA, CARTA, and ALMA Development teams, we identified work areas in which we could make lasting progress.

At the end of the project we have developed the CARTA components for Interactive Clean using the new CARTA architecture. These are consistent with the original design, with some modifications reflecting the changing software landscape. However, since CASA interprocess communication technologies are not yet selected, we are unable to complete the full set of deliverables.

2. The Interactive Cleaning Project

This document presents the results of the ALMA Development Study *Cleaning up Interactive Cleaning*, which was supported during Cycle 4 of the North American ALMA Development Program. The overall goal of the study was to implement interactive cleaning functionality in the Cube Analysis and Rendering Tool for Astronomy (CARTA) tool. CARTA has been developed as a replacement for the current CASA viewer. The primary objectives of the CARTA project are to ensure we have a modern visualization client capable of meeting the needs for ALMA for the foreseeable future. In the Quality Assurance reviews of CARTA, the interactive cleaning use case was identified as a growing gap in functionality for many users where CARTA did not provide a solution (being out of scope of the original project) and the CASA solution was deemed increasingly inadequate.

Radio interferometers such as the VLA and ALMA provide high resolution imaging of astrophysical emission at the expense of incomplete sampling of Fourier frequencies in the image. The only data recorded by the interferometers corresponds to the projected baseline separations between antennas at the time of observations. To alleviate this missing information problem, astronomers use deconvolution techniques to interpolate in these missing data, providing an image suitable for astrophysical analysis. Such deconvolution is an ill-defined problem; there are formally an infinite number of sky models that are consistent with a given data set. However, this space of possible models is dramatically reduced by assumptions about the nature of the sky emission.

One common assumption is that the emission is confined to specific regions of the image in user defined regions known as *clean boxes*. By only adding clean components in regions where signal is likely, the deconvolution process becomes significantly more stable. Thus, the best-practices approach to deconvolution is to use the clean algorithm and to define clean boxes to stabilize the deconvolution. These clean boxes are difficult to establish prior to imaging the data, so an interactive cleaning approach is used. In the interactive clean model process, a dirty (no deconvolution) or partially cleaned image is displayed to the user and that user defines regions using a graphical user interface (GUI) that appear to be significant signal. Then the input parameters of the deconvolution algorithm can be changed by the user to maximize stability.

Currently, this interactive cleaning functionality is provided by a dedicated GUI tool within the CASA environment that uses components of the CASA viewer to control the clean process. The goal of this project is to provide a replacement to this functionality using the new CARTA viewer.

2.1 Project Goals

At the outset, the proposal outlined three main deliverables.

1. Provide region functionality within CARTA that could be used to represent clean boxes and other region functionality within the viewer. This was necessary for the GUI tool to manipulate the locations, sizes, and number of clean boxes.
2. Provide a CARTA-based Interactive Cleaning Tool that would be used to control interactive cleaning through the CARTA user interface. This interaction would take place over

3. Build an interface to remotely control the CASA deconvolution software `clean()` using remote process communication. The originally planned pathway was to use the `dbus` package, for which there was a pre-existing interface already designed and partially implemented.

We also established a variety of stretch goals to improve the interface to the deconvolution software and take advantage of recent advances in both CASA and in CARTA's capabilities.

3. Project Summary

This project was completed at the University of Alberta in coordination with the CASA Software Group at NRAO, the ASIAA CASA Development Center (ACDC) in Taiwan. The project was managed by the University of Alberta.

3.1 Project Personel

The development team at the University of Alberta consisted of the PI (Erik Rosolowsky) and a , a developer hired at the University of Alberta. The Alberta software development team interacted primarily with the CASA team at NRAO and the ACDC. At NRAO, the primary contacts were Urvashi Rau (working on the deconvolution software) and Jeff Kern (outgoing CASA team lead for the initial 6 months of the project). We interacted with all of the ACDC team, with Kuo-Song Wang being the main point of contact.

The development study primarily funded the salary for James Dassoulas and travel to meet the other CARTA team members.

3.2 Development Phases and a Changing Software Landscape

The Interactive Cleaning software was developed in several stages, shaped by reactions to a changing software landscape. The following summarizes the development phases that took place during the funded activities in chronological order.

1. *Region Development* — Prior to meeting with the CASA software team, our initial development focused on implemented regions that could be manipulated in the CARTA v0.8 GUI (the version of CARTA delivered to NRAO). We contributed software that manipulated all the basic region shapes as described in the original proposal and could be used as clean boxes in Interactive Cleaning. We also developed a propotype Interactive Clean GUI in CARTA.
2. *CARTA Re-Architecture* — On receiving delivery of the CARTA software package, the ACDC team evaluated the current state of the software and came to the conclusions that a major re-architecture of the package would be necessary for effectively developing at their site. This led to a significant delay in the release and revision of CARTA v1.0, but critically for the Interactive Cleaning project, there was not a clear piece of software for which Interactive Cleaning tools could be developed. Most of our initial progress toward integration into CARTA was unable to be used in later stages of the project. Given the re-architecture plans, we focused instead on developing the interface into CASA, that would be integrated into whatever GUI CARTA developed into.
3. *Developing CASA dbus Interprocess Communication* — After meeting with the CASA team, we began development of a `dbus`-based protocol for controlling the clean process. While `dbus` control was partially implemented in CASA, it was discovered to be no longer compatible with the current implementation of clean. We identified a work path that would be required to bring the CASA into use. This project was placed on hold while the new CASA lead (Ryan Raba) came into the position and could evaluate the utility of the work. With members of the CASA team, we worked to compile a version of CASA with a partial `dbus` interface so we could demonstrate communication with CASA.

4. Interprocess Communication Revisions in CASA — After working on dbus-based commmunication for a while, we received word from the CASA group that dbus would not be used in future CASA development at that the team was evaluating different interprocess communication (IPC) protocols. Our dbus based work and CASA modifications were therefore obsolete. On consultation with the CASA team and the ALMA Development program, we shifted our efforts to evaluating the needs of an IPC protocol for running the Interactive Cleaning deliverables. We focused on evaluation of the CASA team's favoured technology `gRPC`, which was found to be suitable for the Interactive Cleaning Process. We developed a prototype `gRPC`-based protocol for Interactive Cleaning which has been committed to the CARTA code base.
5. *GUI Development and Partial Implementation* — Given the original project duration had been reached and decisions at ACDC and CASA rendered much of our original work immediately obsolete, we had minimal development success. However, we filed a request for a no-cost extension for an additional four months of development. The timing was favourable since ACDC had advanced enough of their re-architecture to make it possible to develop the Interactive Cleaning GUI using the new development process. In the final phase of the project, we implemented a basic GUI as well as a template control protocol that connects to CASA, once the IPC strategy is finalized by the CASA group.

3.3 The Interactive Cleaning Project Status

Because of the shifting software development landscape on both the CASA and CARTA side, we did not fully achieve the basic goals outlined in the proposal, facing delays driven by reacting to a series of changes in the CASA development team and changes in the CARTA software package. However, the project yielded several tangible results that have been integrated into the CARTA software suite and documentation that has been transmitted to the CARTA team. Project code is integrated into the CARTA software repository[1].

During the final phase of development described above, our team contributed a few key components.

1. Basic Interactive Cleaning GUI — The example GUI is shown in Figure 1. The basic layout contains functionality to manipulate the parameters in the deconvolution process such as the threshold, number of iterations, and cycle factor. The GUI has region drawing control and the ability to connect to clean process diagnostics to monitor convergence of the deconvolution process. The GUI also anticipates the ability to connect to remote servers, utilizing the CARTA ability to visualize remote data (LOCAL vs REMOTE toggle). The GUI has been developed in a modular fashion using the react.js framework. This is consistent with the rest of the CARTA GUI development.
2. CARTA Backend Development — All CARTA GUI components connect to C++ software which executes the calculations required to visualize the data. This C++ is known in the project as the "backend" and it tracks the state of the visualization, manages access to data, and IPC. Within the backend, we have developed the software to track the Interactive Clean software state and form the commands to send to CASA. Since the CASA IPC protocol is

[1] github.com/cartavis/

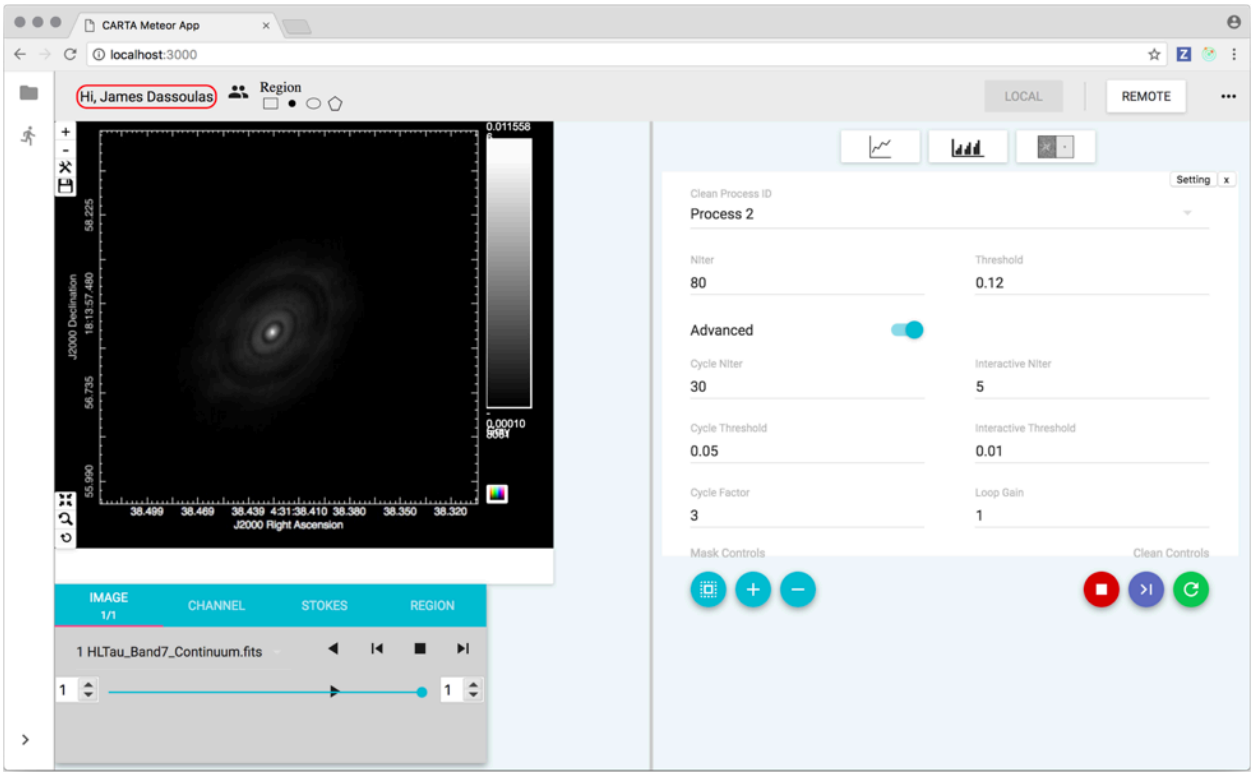

Figure 1: Basic interactive cleaning GUI implemented in the latest CARTA front-end framework. The layout has basic controls of the clean process, diagnostic plots for clean performance, and the ability to manipulate CARTA regions.

not yet established, we have not fully implemented the CARTA end of the IPC chain. However, preliminary tests indicate that CARTA representation can be effectively transmitted to CASA via gRPC provided that is the technology choice.

3. CARTA Connectivity — We have also completed the software that synchronizes the GUI components with the backend state. This is particularly key when the GUI is hosted on a different computer from the backend and the CASA software, as will be the case when controlling a remote server.

We also retained much of the code from our initial development of regions, where parallel functionality was developed in CARTA, supporting the interactive clean deliverables. Of note, we achieved one of our stretch goals allowing regions to be smoothly extrapolated across velocity channels, which is a new addition to functionality.

3.4 Next Steps

While we have made rapid progress in the final four months of the project, completing the originally proposed deliverables requires a few next steps.

1. Connection to CASA IPC — Commands for CASA controlled from within CARTA will need to be sent to CASA via whatever solution CASA ultimately settles on.

2. Translate CARTA regions in to CASA mask files — Using IPC and CASA's internal tools, developers will need to translate the current regions in the CARTA GUI into mask files used in the Interactive Cleaning process. Since the tools are in place within CASA to turn region files into masks, this step primarily requires ensuring the translation to the CASA region format is robust.
3. Connect to multiple clean processes — CASA is currently developing deconvolution software that can run multiple instances of cleaning simultaneously. The CARTA software backend will need to be able to support the manipulation of cleaning parameters for multiple processes. While this is allowed for in the current code, it will need to be refined once IPC control of clean processes is finalized by CASA.
4. Development of a Settings Pane — Most CARTA tools have the ability to set user preferences and the project should undergo a requirements capture phase and implement a settings panel for consistency across the application.

4. Performance Review

This section reviews the performance of the Interactive Cleaning project with respect to original project specifications, project timeline, and project budget. Because this is a software project and is governed by labor costs, these issues are inextricably linked. Overall, the Interactive Cleaning project was delayed in implementation and did not reach its originally stated goals because of evolving software development landscape. To ameliorate this shortfall, the project has altered scope and timeline with no change to budget in consultation with the ALMA Development Program. These decisions were undertaken to provide work that will ultimately be integrated into the CARTA and CASA interface.

4.1 Performance to Specifications

As outlined above, we were unable to achieve the full set of deliverables because of the shifting software development landscape. However, given we were able to achieve a significant fraction of the project's goals in only four months of work, this points to the ease of development in the new CARTA development environment. We anticipate that the project could readily be brought to completion once CASA IPC control of clean processes is implemented using the new protocols.

4.2 Performance to Timeline

The project was originally scheduled to run for 12 months and we requested a no-cost extension to continue work on the CARTA components. While there was budget remaining in the project, we are unable to continue employing James Dassoulas in his current position because of union rules at the University of Alberta. The position was offered as a short-term position and we are unable to convert it to a long-term position without provoking a labour grievance.

4.3 Performance to Budget

The project did not use the fully requested budget and NRAO will not be charged for the remainder of the cost. See financial statements for details.

5. Project Closure and Transition to NRAO

The CARTA project has transitioned to the ASIAA CASA Development Center software group for completion when CASA IPC protocols are finalized. The transition has been facilitated by the ongoing work with the CASA and CARTA groups throughout the entire project. The delivered products include:

- Access and ownership of the open source software on github.
- Documentation including
    - Project reporting (this report and financials reporting)
    - Development framework documentation (Delivered to the ALMA CASA Development Center in Taiwan)

The PI for CARTA development, Erik Rosolowsky, is a member of the CARTA Science Advisory Team and will continue to help guide development on Interactive Cleaning.

6. Lessons Learned

While the project was a mixed success, this largely stemmed from bad timing of the project to complete the work at a time of significant transition within the CARTA and CASA group. Given the major changes in handoff and redesign of the CARTA project combined with changing leadership within the CASA team made the period of performance not ideal. It is clear that given the rapid progress made in the final stages of the project, it would certainly have been feasible to complete the work had the project started later.