Image Differencing Audit

In early Spring of 2021 the AP team conducted an extensive audit of the image differencing algorithms and configurations available in the LSST Science Pipelines. The goals of the exercise were to identify any major errors in our implementation of image differencing, to make progress towards completing milestone DM-AP-12, and to make the switch internally to using the Gen 3 middleware for our data processing. While we were ultimately successful in converting all of the the Alert Production pipeline to Gen 3, it should be noted that the conversion consumed the bulk of the team's time in the first two months. Milestone DM-AP-12 states that the Alert Production pipeline must be agnostic to the PSF of the template, which requires at least one of the following image differencing configurations: using Alard&Lupton and convolving the science image, using Alard&Lupton and preconvolving the science image, or any form of ZOGY. Unfortunately, each of these configurations currently suffers from significant problems, so we have devoted the remainder of our time in the sprint and in follow-up tickets to diagnosing and fixing those errors.

1. Data selection

Repository	`/datasets/hsc/gen3repo/rc2w50_ssw02/`
Collection	`HSC/runs/RC2/w_2020_50`
Tract	9813
CCDs	49, 50, 57, 58, 65, 66

Table 1: Location and specification of the dataset on `lsst-devl`

For this testing, we focused on processing a subset of the HSC Cosmos survey from RC2. The observations from each band were grouped according to their seeing, with separate templates constructed from visits selected from the best, middle, and worst third. While the templates were constructed for the full focal plane, when running the Alert Production pipeline we used only six neighboring CCDs from the center. These CCDs were chosen to avoid bright stars and edge effects. We further restricted our analysis to g- and r-bands, with the specific visits used listed in Table 2 below.

	g-band		**r-band**	
	Included visits	**coadd PSF size (pixels)**	**Included visits**	**coadd PSF size (pixels)**
Best third	11704, 11702, 11694, 11698, 11692, 11696	4.616	23694, 1208, 1218, 23692, 1220	3.005
Middle third	11700, 11706, 11690, 11708, 29340, 11710	5.076	23704, 1216, 1204, 1214, 23718	3.386
Worst third	29324, 29336, 11712, 29326, 29350	6.581	23706, 23716, 1202, 1210, 1206, 1212	4.160

Table 2: Lists of the visits included in each template.

2. Pipeline configurations

Using our test dataset we explored the most common configurations of image differencing. With our standard Alard&Lupton style of image differencing we ran with the decorrelation afterburner turned on or off, preconvolution turned on or off, and convolving either the science image or the template. In each case, the full set of visits was used as science images against the best, middle, and worst seeing templates for both bands in order to test the cases when the science image or the template has greater seeing. The same tests were performed for ZOGY as well, though in that case the only variable configuration was whether preconvolution was turned on or off. For ZOGY, turning preconvolution on means that the "score" image is returned. The "score" image should be suitable for detection and measurement, but requires downstream modification of those algorithms to be handled properly. We found that multiple settings were universally applicable, and these have since been raised to defaults:

~~DM-29869~~ - Make doScaleDiffimVariance=True the default in ImageDifferenceTask DONE . The only changes in the settings between the different pipelines are summarized below in Table 3. Note that the detection threshold is set to 5.5 when decorrelation is turned off, and 5 when it is on.

	Modified `imageDifference` settings
A&L	`doDecorrelation=False` `detection.thresholdValue=5.5`
A&L with decorrelation	`detection.thresholdValue=5.0`

A&L convolve science image	`convolveTemplate=False`
	`doDecorrelation=False`
	`detection.thresholdValue=5.5`

A&L convolve science image with decorrelation	`convolveTemplate=False` `detection.thresholdValue=5.0`

A&L preconvolution (maximum likelihood image)	`doPreConvolve=True`
	`doDecorrelation=False`
	`detection.thresholdValue=5.5`

A&L preconvolution with decorrelation	`doPreConvolve=True` `detection.thresholdValue=5.0`
ZOGY difference image	`detection.thresholdValue=5.0`
ZOGY preconvolution (maximum likelihood image)	`doPreConvolve=True` `detection.thresholdValue=5.0`

Table 3: The modified settings used for each pipeline configuration.

3. Results

The standard configuration of image differencing using Alard&Lupton with no preconvolution and convolving the template works well, as expected. However, if the science image has better seeing than the template we have no good options if we wish to avoid deconvolution. These configurations appear to never be used, and in many cases the pipelines simply crash. In Table 4 below I have summarized the status as of March of 2021, as well as the Jira tickets we have created to address the problems. The investigations into the root causes of the problems are ongoing, so I will provide updates when we have significant results to report. For the configurations that run successfully to completion, I quantify in Table 5 below the false positive rates that lead to the classification of the results as 'poor'. For this simple analysis, I have assumed that most of the detections on the difference images are false detections.

Pipeline runs to completion	Reported failure fixed, but pipeline not re-run	Full pipeline runs to completion, but results poor	Full pipeline does not run to completion	Invalid configuration (no further work planned)

				Status as of March 2021		Current status (August 2021)	
Algorithm	**Preconvolution**	**Image to convolve**	**Decorrelation afterburner**	**Science PSF > template**	**Science PSF < template**	**Science PSF > template**	**Science PSF < template**
A&L	No	Template	No	Functional	Deconvolution	Functional	Deconvolution
A&L	No	Template	Yes	Functional	Deconvolution	Functional	Deconvolution
A&L	No	Science	No	Deconvolution	No failures	Deconvolution	~~DM-29373~~ - Debug option to convolve the science image DONE
A&L	No	Science	Yes	Deconvolution	No failures	Deconvolution	~~DM-29490~~ - Debug decorrelation afterburner when convolveTemplate=False DONE ~~DM-29373~~ - Debug option to convolve the science image DONE
A&L	Yes	Template	No	100% failure rate	100% failure rate	~~DM-29419~~ - Debug preconvolution option in image differencing INVALID ~~DM-29965~~ - Persist the preconvolved Alard-Lupton difference image as a gen3 dataset DONE	~~DM-29419~~ - Debug preconvolution option in image differencing INVALID ~~DM-29965~~ - Persist the preconvolved Alard-Lupton difference image as a gen3 dataset DONE
A&L	Yes	Template	Yes	95% failure rate	95% failure rate	~~DM-29489~~ - Debug decorrelation afterburner when doPreconvolve=True DONE	~~DM-29489~~ - Debug decorrelation afterburner when doPreconvolve=True DONE

ZOGY	No	N/A	No	Deconvolution ~10% failure rate	Deconvolution ~10% failure rate	Deconvolution	Deconvolution
ZOGY	Yes (results in returning the "score" image for detection and measurement)	N/A	No	100% failure rate	100% failure rate	~~DM-29495~~ - Persist the zogy score image as a standalone datatype in gen3, clarify runtime options DONE	~~DM-29495~~ - Persist the zogy score image as a standalone datatype in gen3, clarify runtime options DONE

Table 4: Functional status of each pipeline configuration as of March 2021, and the current status with the associated Jira tickets.

Algorithm	Preconvolution	Image to convolve	Decorrelation afterburner	Relative false positive rate (March 2021)	Diffim variance median (March 2021)	Relative false positive rate (August 2021)	Diffim variance median (August 2021)
A&L	No	Template	Yes	1X	486.	1X	486.
A&L	No	Science	No	~10X	140.	(not re-run)	(not re-run)
A&L	No	Science	Yes	~20X	140.	2.5X	640.
A&L	Yes	Template	No	(no results)	19.6	(not re-run)	(not re-run)
A&L	Yes	Template	Yes	(no results)	535.	1.4X	449.
ZOGY	No	N/A	N/A	~4X	9.42	(not re-run)	(not re-run)
ZOGY	Yes	N/A	N/A	(no results)	0.002	(not re-run)	(not re-run)

Table 5: Summary statistics from the APDB and difference images for each pipeline configuration as of March 2021.

Further details and plots from each pipeline configuration can be found in Meredith's sprint closeout notebook.

4. Future directions

The primary use of image differencing will continue to be Alard&Lupton using the decorrelation afterburner and convolving the template, which is a well-tested and robust path through the code. This path is also functional in the case where the science image has better seeing than the template, though the false positive rate will likely be higher when deconvolution is required. The alternate pipeline configurations all require some work, though from Table 5 above it appears likely that many of the problems may be due to improper handling of the image difference variance plane. We do not have any work planned to refine any of the configurations that involve deconvolution (shaded grey in Table 4 above).

Proposed areas to focus on for improvement:

1. We will continue working on ~~DM-29373~~ - Debug option to convolve the science image DONE which should allow us to convolve the science image rather than the template when it has better seeing. We believe the decorrelation afterburner has been fixed to work correctly in this case with ~~DM-29490~~ - Debug decorrelation afterburner when convolveTemplate=False DONE , but this alone does not fix the high false positive rate.
2. Preconvolution potentially solves many problems, since convolving the template using standard Alard&Lupton should work without deconvolution regardless of the seeing of the science image or template. The resulting maximum likelihood image should be close to equivalent to the ZOGY "score" image, so these data products could be persisted and used for downstream source detection and measurement.