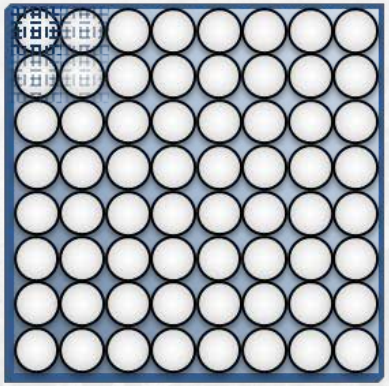

LFIT v2

LIGHT FIELD IMAGING TOOLKIT V2

An Introduction to the Light Field Imaging Toolkit (v2.40)

Current developers: Mahyar Moaven and Dr. Chris Clifford

Many thanks to Dr. Brian Thurow, Dr. Tim Fahringer, Dr. Paul Anglin, Dominic Hildebrandt, and Chelsea Thomason for extensive discussions and various contributions that made this toolkit possible, and to previous developers Jeffrey Bolan, Kyle Johnson, and Dr. Elise Munz Hall

Questions? Contact Mahyar Moaven at mzm0210@auburn.edu

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Basic overview of LFITv2 capabilities

INTRODUCTION

Primary Features

- The Light Field Imaging Toolkit (LFIT) facilitates quick processing of plenoptic images
  - Perspective Shifts
  - Refocusing
  - Generation of Perspective Sweep Animations
  - Generation of Refocusing Animations
  - Focal Stack Export

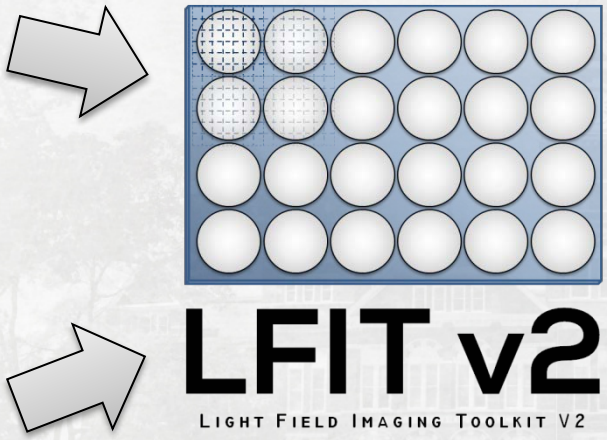
Toolkit Overview

- Two primary ways to use the toolkit
  - Single Image (GUI) mode
    - User interface provides options to load and process a single plenoptic image at a time
    - User can then adjust parameters in the interface before exporting perspective shifts, refocused images, etc.
  - Batch Processing (script) mode
    - User edits a script file
      - Folder of input images is selected for automatic sequential processing
      - Output parameters for perspective shifts, refocusing, etc. are defined in the script beforehand
      - Following calibration, program requires no user input and runs automatically through all the images in the folder.

Example Workflow

100 calibration images

raw experimental images



- Perspective shifts
  - Variety of image formats
- Refocused images
  - Variety of image formats
- Perspective sweep animation
  - GIF or video file
- Refocusing animation
  - GIF or video file
- Focal stack
  - Output a series of refocused images

• *One also needs to determine the magnification of the images. An easy way to do this is by capturing an image of a ruler.*

Using the Single Image (GUI) mode for processing plenoptic data

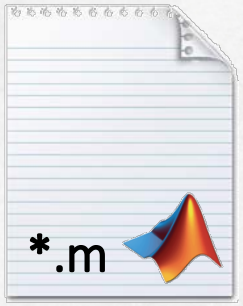
QUICK START GUIDE

Installation

- Obtain latest LFITv2 zip file and extract the contents
- Option #1:
  - Run the SETUP.m file to automatically uninstall any old versions of the toolkit and install the new toolkit
- Option #2:
  - Delete any existing LFITv2 folders inside the MATLAB user directory*
  - Copy the LFITv2 folder from the zip file to the MATLAB user directory*

*MATLAB user directory is typically C:\Users\<username>\Documents\MATLAB. To check, type userpath at the MATLAB command line.

Program File Structure



LFITv2_40_main.m

-Main program that invokes the GUI interface(s)
-Also contains the batch processing script section (user-editable)

-The user is encouraged to save new versions of this script when creating batch files (see later section). Think of this initial version as a template. The script name does not matter for this file.

LFITv2

-Contains all the function files that compose the toolkit
-Placed in MATLAB user directory

-To modify functions, user may create a copy of LFITv2 in the same folder as the main program. The program will use the functions from the local /LFITv2/ folder instead.

toolkitpathv2.m

-Required function that locates LFITv2 folder

SETUP.m

-Optional script used to install the locally extracted version of LFITv2

samplePath.txt

-Optional: An example custom perspective sweep path

Required GUI components

LFITv2_GUI_SinglePanel.fig
LFITv2_GUI_Prerun.fig

LFITv2_GUI_SinglePanel.m
LFITv2_GUI_Prerun.m

LFITv2_Documentation.pdf

header.png
refocusRef.png

Optional GUI components

lastrun.cfg

lastGUI.gcfg

- These are config files saved after each run to remember last used settings.

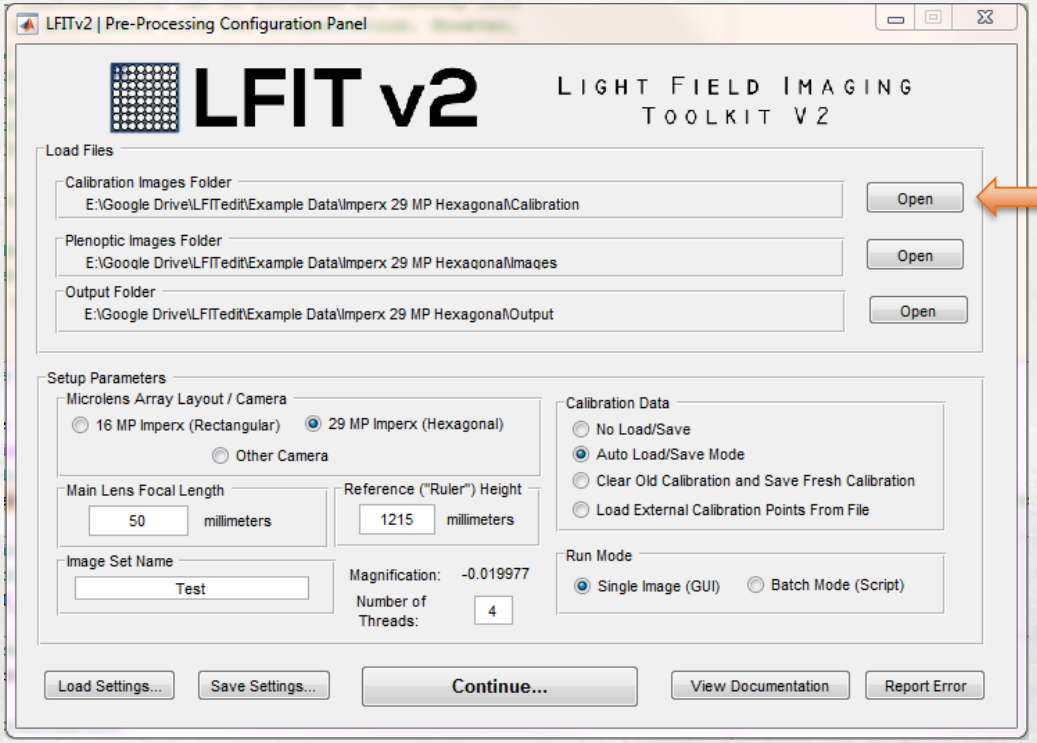
All files shown above should be located in the same folder, except for the LFITv2 function folder which should be located in MATLAB's userpath.

Running LFITv2

- User should have the calibration images (to be averaged) in one folder and the image(s) to be processed in a separate folder
- Open the main program file (nominally LFITv2_main.m) in MATLAB.
  - If running in Batch Mode, user will need to edit this file to configure batch processing (see later section).
- Run the script to open the pre-processing configuration panel.
  - This interface panel is used to set up file paths and other basic parameters

Pre-Processing Configuration Panel

For a given camera setup in an experiment, the aperture should be stopped all the way down (ie f/16 or f/22) and typically 100 TIFF images taken of a white surface. These images record the center of each microlens—a key piece of information used in LFITv2.



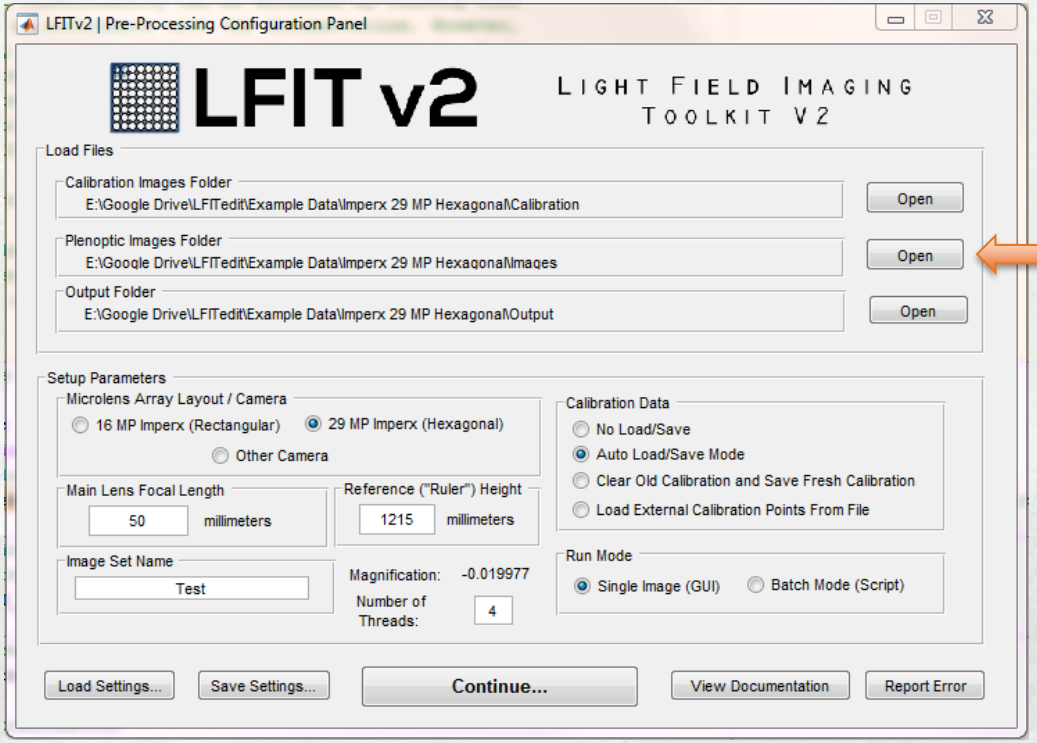
Select the calibration folder from the pop-up dialog.

- #1) User opens the folder of calibration TIFF images.

Pre-Processing Configuration Panel

This folder parameter is more important for the batch processing mode, as batch mode will cycle through all images in the folder.

For the single image GUI mode, the user can select any image (within or without this particular folder).



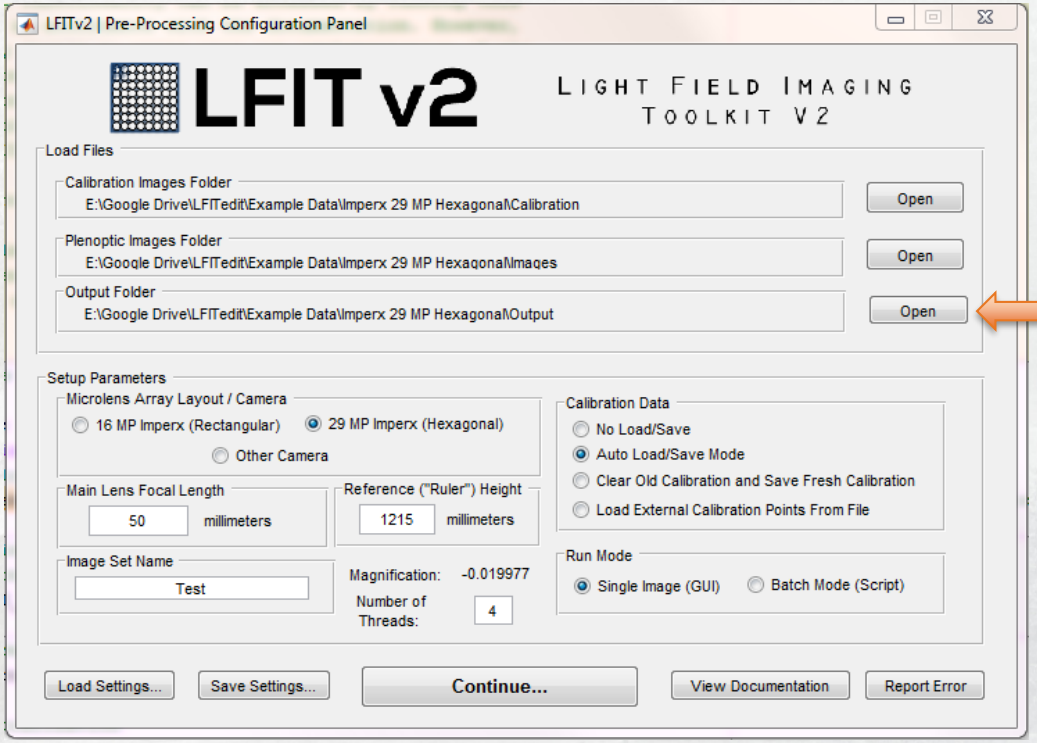
Select the experimental images folder from the pop-up dialog.

- #2) User opens the folder of the raw plenoptic image(s) to be processed.

Pre-Processing Configuration Panel

Typically, the user will want to create a new folder to contain the outputted images. This can be done from the Open prompt in the GUI.

If unsure what to choose, a common place to output exported images is to a subfolder within the plenoptic images directory (ie /Output/).

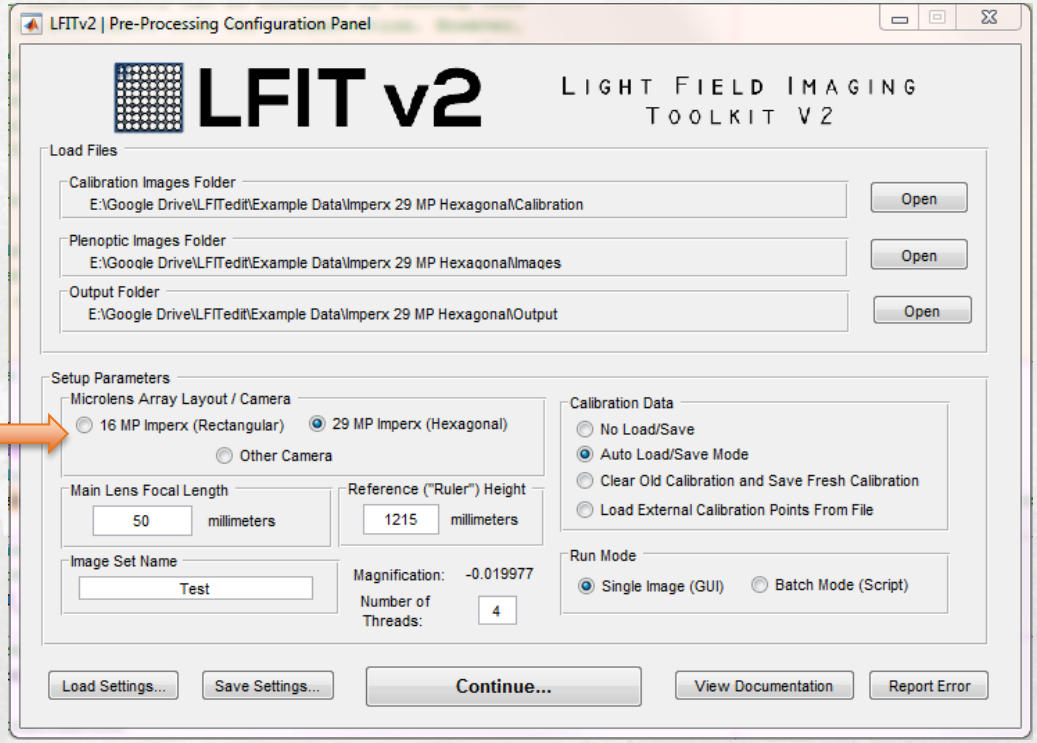


Select the desired output folder for any exported images.

- #3) User selects a folder for exported images to be outputted to.

Pre-Processing Configuration Panel

Select the camera used in the experiment.



Select whichever camera that was used to capture the plenoptic images to be processed.

The 29 MP Imperx has a hexagonally arranged microlens array.

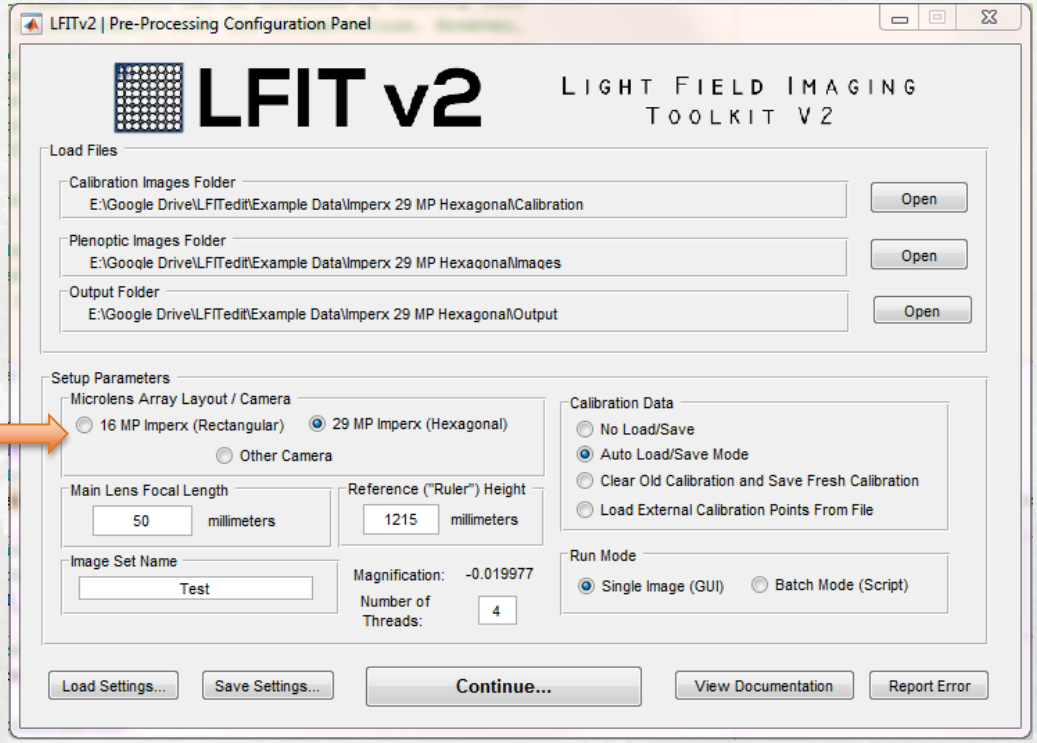
The 16 MP Imperx has a rectilinear grid of microlenses.

- #4) User selects the camera used to capture the plenoptic images.

Pre-Processing Configuration Panel

The main lens focal length entered here is just the focal length of the main lens. Do not include extension tubes.

Enter the focal length (in millimeters) of the main lens.



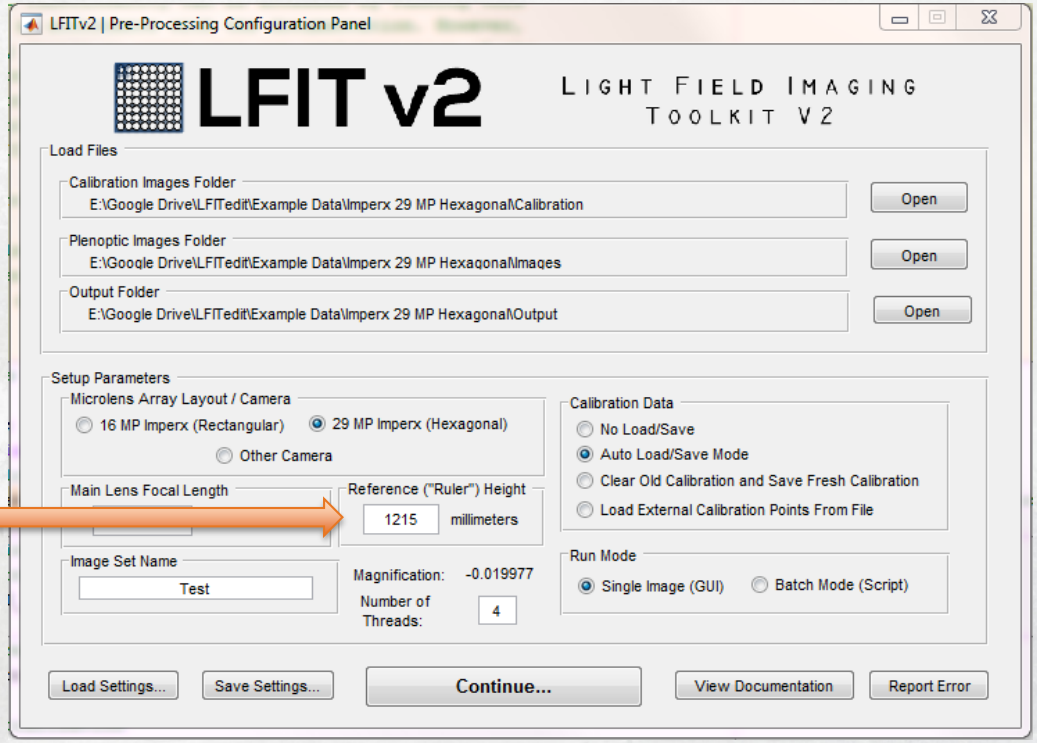
Typical focal lengths might be 50 mm, 100 mm, 250 mm, etc. This will be indicated on the lens itself.

Prime lenses have a fixed focal length and are recommended for experiments. Telescopic lenses are discouraged as it is often unclear what the exact focal length of the lens is when set at some intermediate zoom.

- #5) User enters the focal length of the main lens.

Pre-Processing Configuration Panel

Enter the height (in mm) of a ruler placed at the nominal focal plane of the given experimental setup.

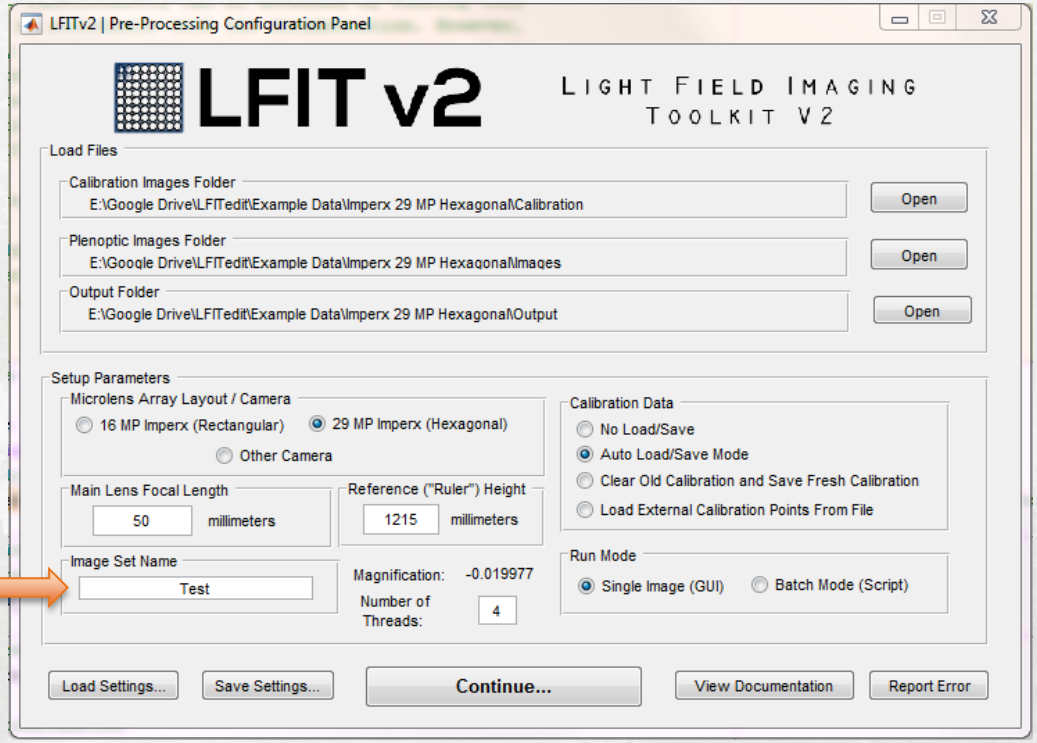


For a given experimental setup, place a ruler at the nominal focal plane of the camera setup. Ideally it will fill the image frame. If it doesn't, the user will need to figure out how tall it would be if it did fill the entire frame. Record the height in mm and enter it here.

The magnification text below will update depending on the value you enter.

- #6) User enters the reference ("ruler") height to determine the magnification.

Pre-Processing Configuration Panel



Enter a name for the given experimental image set.

This Image Set Name is used as a prefix on exported files, so keep it of reasonable length.

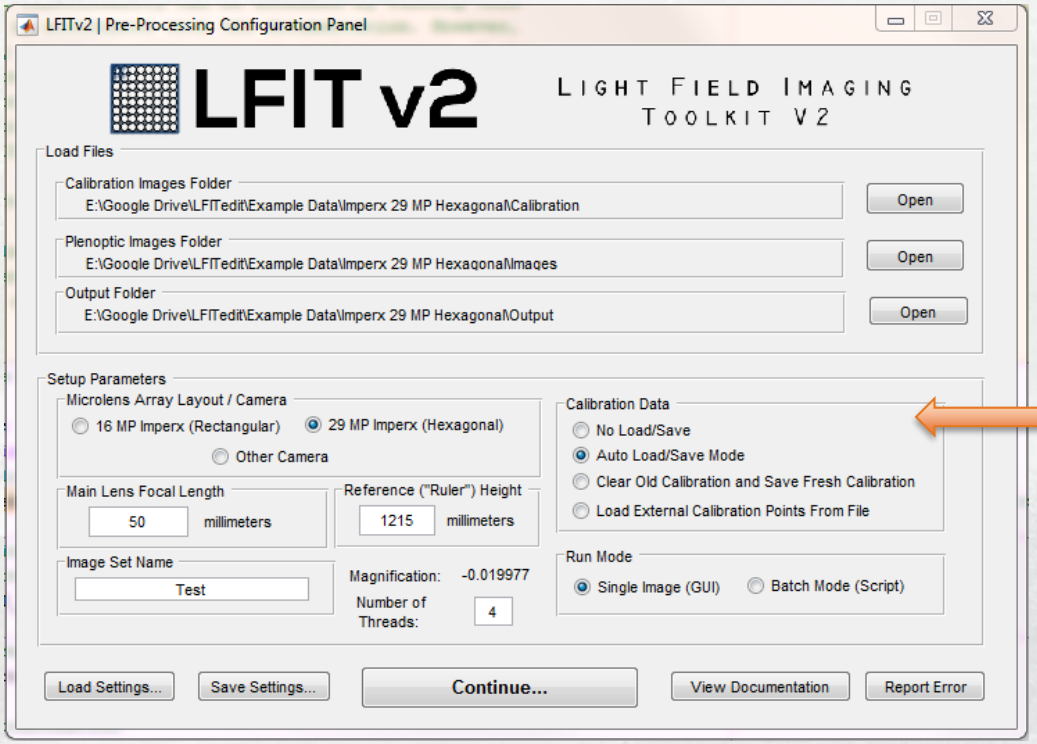
Also, this name is used to label calibration data saved if using the calibration save options (next slide).

- #7) User enters a name for the set of plenoptic images to be processed.

Pre-Processing Configuration Panel

Auto Load/Save Mode will attempt to load calibration data in the Calibration Images folder defined above that is labeled with the Image Set Name. Otherwise, it recomputes the calibration and saves it with the Image Set Name in the Calibration Images folder.

Clear Old/Save Fresh will attempt to delete saved calibration data associated with the Image Set Name in the Calibration Images folder. It then recomputes and saves calibration data as above.



No Load/Save always recomputes the calibration data every time LFIT is run.

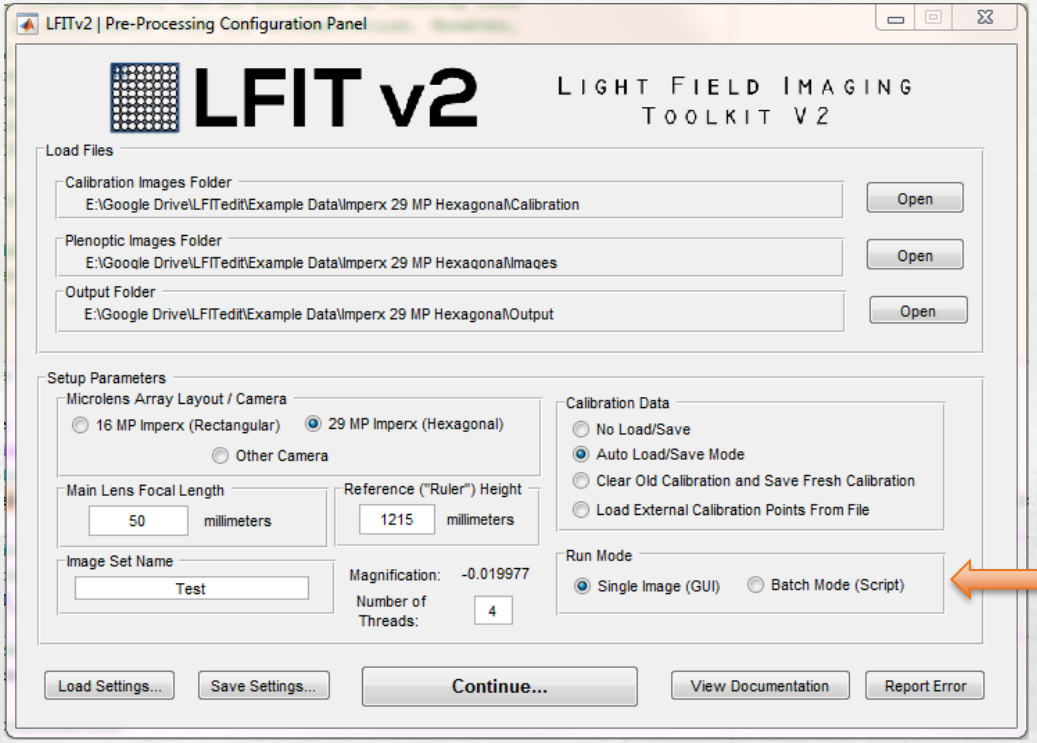
Select a calibration option from the button group.

- #8) User selects a calibration data save/load mode option.

Pre-Processing Configuration Panel

Single Image (GUI) mode presents a graphic user interface with buttons and checkboxes etc. to facilitate quick processing of individual plenoptic images.

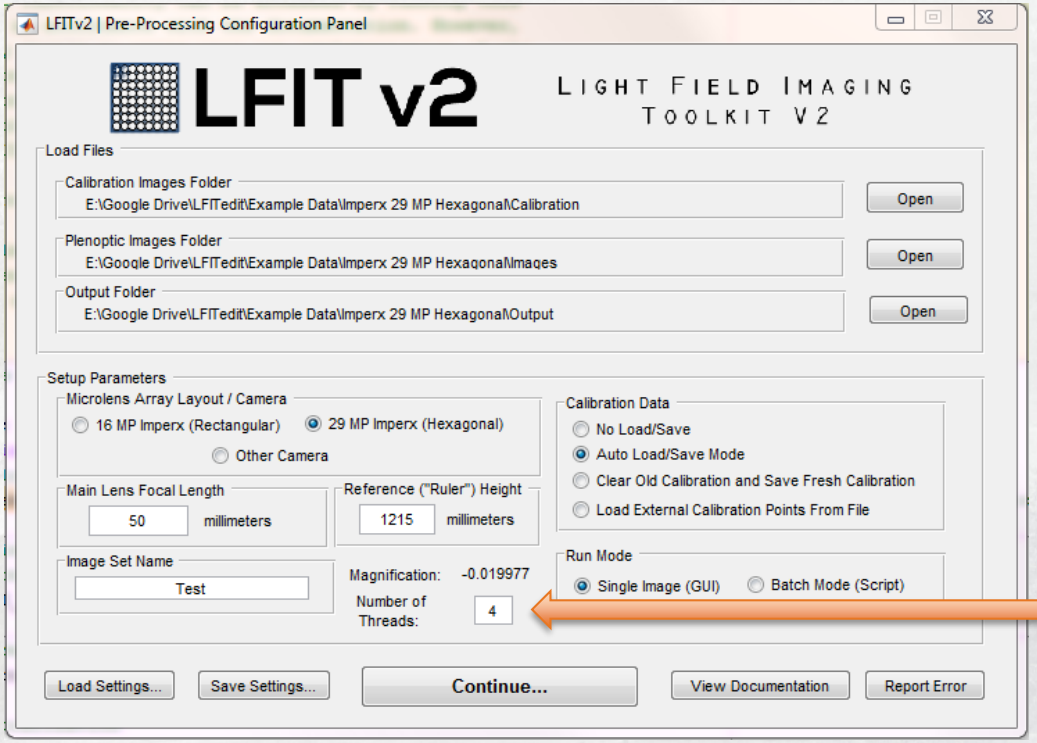
Batch (Script) mode executes the script found in the bottom portion of the LFITv2_00_main.m (or equivalent) file. This allows for processing of many plenoptic images in an automatic, prescribed fashion. See later section on Batch Mode.



Select a run mode option from the button group.

- #9) User selects a run mode for the program.

Pre-Processing Configuration Panel



Select the number of cores to use for processing.

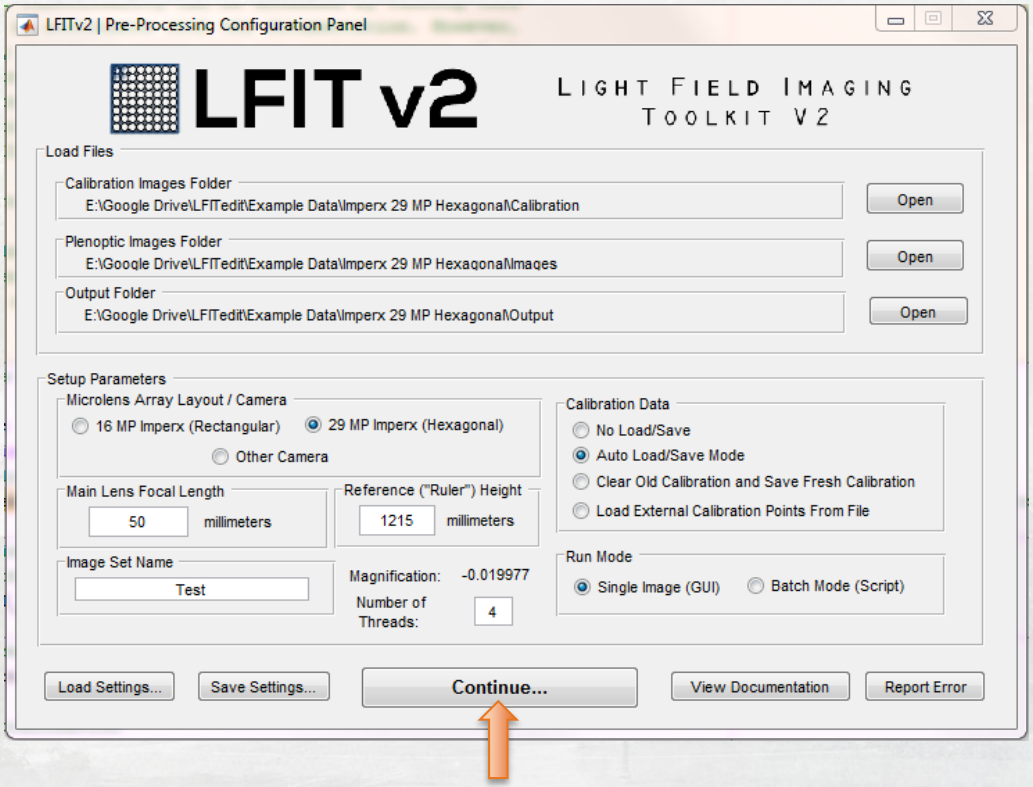
- #10) User selects the number of cores to use (should not exceed the number of physical cores available).

Pre-Processing Configuration Panel

Load Settings and Save Settings permit loading and saving of the parameters defined in this interface panel.

Note that the panel will automatically 'remember' the settings from the previous run.

(The program attempts to load the previous run; if no saved run can be loaded, it simply fills the panel out with defaults.)



View Documentation opens a help file in the PDF viewer installed on the local machine.

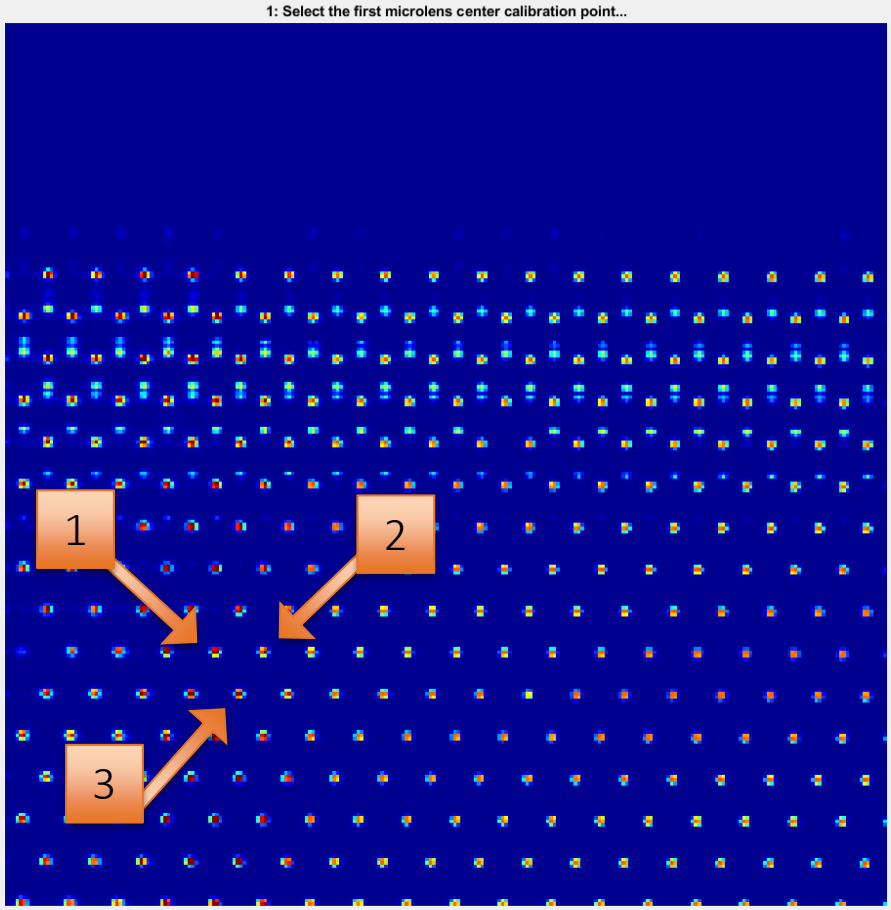
Report Error opens the default email client with a new message addressed to the LFIT developers.

- #9) User presses Continue... to begin.

Hexagonal Calibration

Select three initial calibration points as prompted in the orientation shown, then wait for the calibration to be complete. Based on the resulting calibration figure, select from the menu in the Command Window:

[1] = Accept the calibration (if the calibration appears correct)
[2] = Reject the calibration (if many microlenses are incorrectly or not identified)
[3] = View the full calibration window (if you need to view the entire calibration window to verify the calibration)
[4] = View the corners calibration window (to view the calibration corners again)



Hexagonal Calibration

- If the calibration is rejected, another menu will appear in the Command Window:

[1] = Select new points to recompute fast hexagonal calibration

[2] = Use alternate hexagonal calibration (slower)

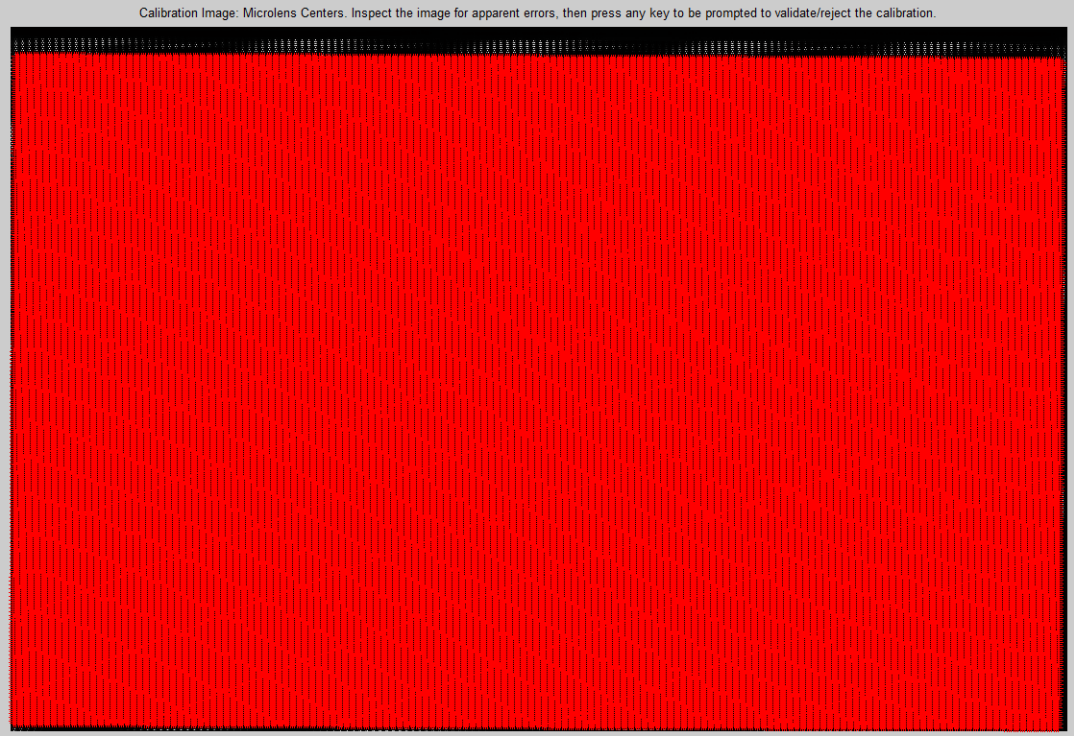
[3] = QUIT

- If the alternate calibration is selected, the user will be prompted for a calibration threshold value.
  - A recommended value is dynamically calculated for the averaged calibration image in the above prompt, but the user may experiment with different values for problematic calibrations
  - Type the desired value and press <Enter>

Hexagonal Calibration

This is an example of a good calibration, excepting the fact that the top is excessively cropped.

This is due to our selecting of an initial point some distance from the top of the image to avoid some artifacts caused by a microlens array that was not completely centered over the image sensor.



The overall pattern looks consistent/uniform from this zoomed out perspective.

The main thing to watch for would be skipped rows or columns; these errors would manifest themselves with an obvious break in the overall pattern or with a distinct repeating pattern. It may be necessary to zoom in to see these abnormalities, however.

Such errors would also be apparent in outputted images, particularly in a ruler image.

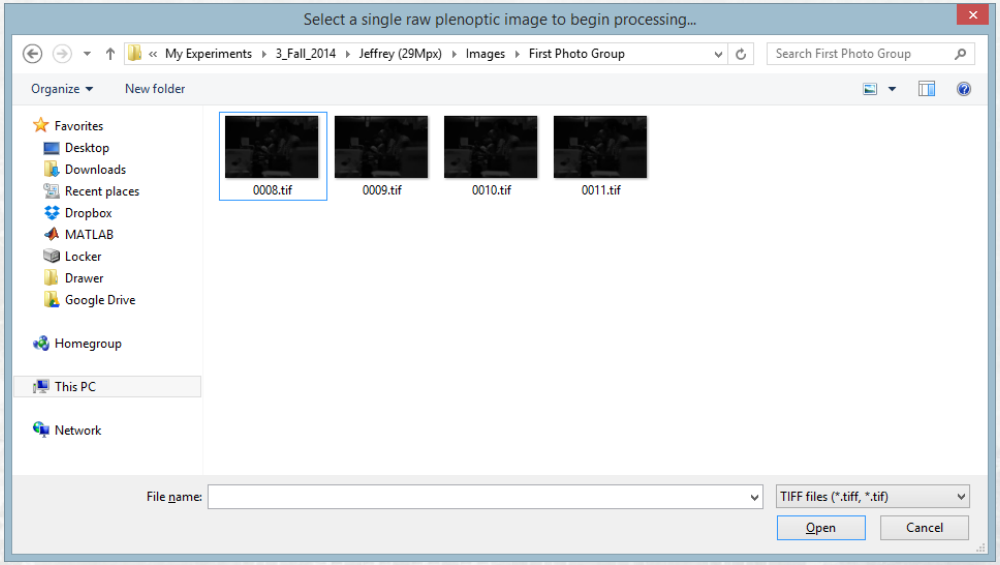
Single Image (GUI) Mode

- The remainder of this Quick Start Guide follows the case of Single Image (GUI) mode with the 29 MP Imperx (hexagonal) camera.
  - There are some slight differences for the 16 MP Imperx (rectangular) camera process, but overall the steps are the same.
  - See later information on Batch Mode processing.
- Also, now begin watching the MATLAB command line output.
  - Warnings, prompts for user input, and estimated wait times during processing steps all may be displayed.

Image Selection

The dialog opens by default in the chosen plenoptic images directory previously defined in the pre-processing interface at the beginning of the program.

After selecting an image, the program interpolates the image data behind each microlens (i.e., the microimage data) onto a uniform (u,v) grid. This hexagonally arranged data is then resampled onto a rectilinear grid.

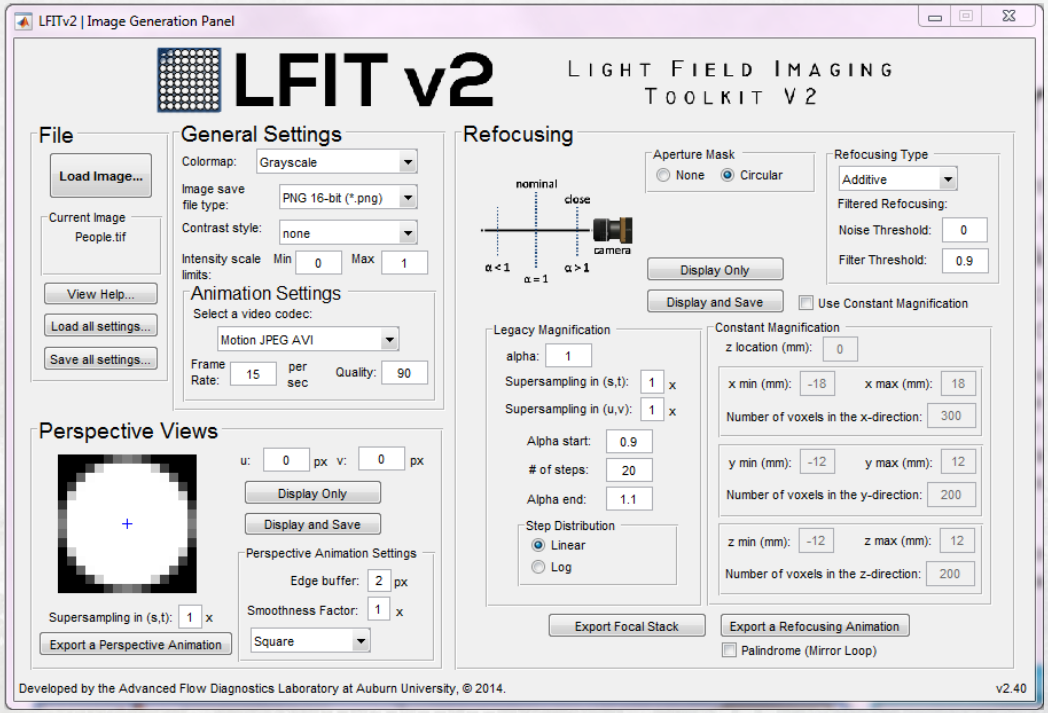


If the user selects an image from a different folder than defined at the start, the program will immediately prompt the user for a new output folder.

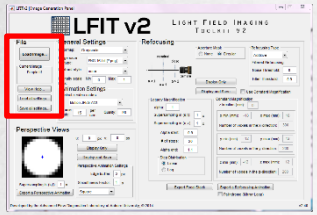
If the user cancels this dialog, the program automatically creates an output folder (/Output/) in the same directory as the selected image. The exact path is then shown in the command line output.

- Select a single raw plenoptic image to process from the dialog, then wait for the interpolation and resampling processes to complete.
  - Observe the command line output for estimated wait times.

Image Generation Panel



- The main image generation interface panel opens after the interpolation and resampling is complete.
- While it may look intimidating, this guide will break it down section-by-section to explain the contents.
  - Also note that every box in the interface has mouse over ("tooltip") text that provides help.



File Selection

Press to load and process a new raw plenoptic image.

Note: This image must still be associated with the same calibration set as used earlier.

Watch the command line output for estimated wait time as it will take some time to process a new image. Refrain from adjusting the interface settings while waiting.

File

Load Image...

Current Image
People.tif

Displays the currently loaded image file name.

Click to open the help file in the local PDF viewer

View Help...

Loads all settings from a file.

Note that the settings are automatically loaded from the previous run when the interface window initially opens. If this auto load fails, defaults are used instead.

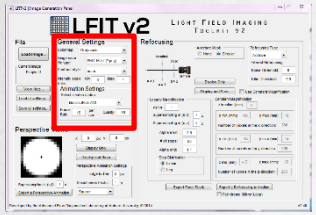
Load all settings...

Save all settings...

Saves all settings in the currently displayed interface to a file.

Note that the currently loaded/processed image data is NOT saved via this option. Also note that the settings are automatically saved when closing the interface figure.

- This section allows for loading/processing a new plenoptic image, viewing help, and saving/loading settings files.



General Settings

Built-in MATLAB colormaps

Select type of contrast scaling to apply:
none: no contrast scaling
slice: each view or slice scaled based on its max/min
stack: each slice or view scaled based on the stack max/min

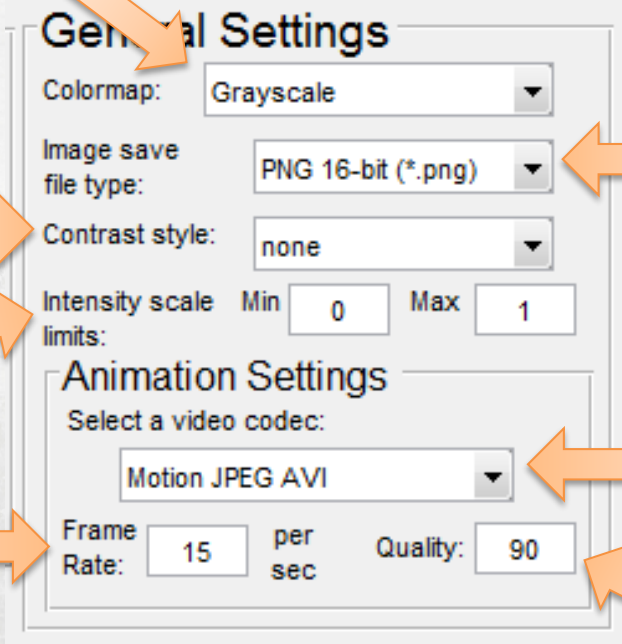
Limits of intensity scaling, between 0 and 1

Integer number.
Typical frame rates:
15=minimum for motion, 24=cinema, 29.97=NTSC, 30=typical, 60=display refresh rate.

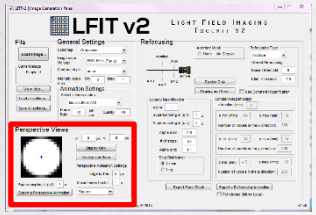
Select a file type to be used in perspective shifts/refocused exports:
BMP
PNG
JPEG
16-bit PNG
16-bit TIFF
(Grayscale colormap recommended when using 16-bit options.)

Video Compression Codec:
MATLAB R2010a or earlier:
Uncompressed, MSVC, RLE, Cinepak
MATLAB R2010b or newer:
Uncompressed, Motion JPEG AVI, Lossless Motion JPEG 2000, Compressed Motion JPEG 2000,MP4 (H.264)

Integer between 0 and 100



- Image and video display and save settings that apply to all generated images



Perspective Settings

- This section permits the generation of perspective shifts of the loaded image.

Plots the currently entered (u,v) coordinates on a simulated microimage of a circular aperture.

Value (in pixels) between:
Rectangular: -8 and +8
Hexagonal: -7 and +7
(decimal values are supported)

Computes and displays a perspective shifted image in a new figure.

Computes, displays, and save perspective shifted image in previously defined output folder.

Value between:
Rectangular: 0 and +7
Hexagonal: 0 and +6
This is a buffer from the edges of the microimages when moving about in the aperture plane during perspective sweep movie generation. The data tends to degrade near the edges, so this is a way to buffer it out. 2 is a typical choice.

Integer value of 1 or greater
1= default smoothness
2 = 2x smoothness
4 = 4x smoothness

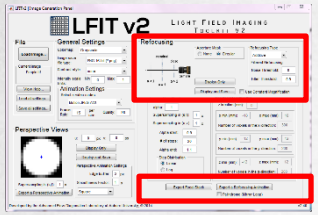
This makes the step size between evaluated (u,v) values finer/smaller, increasing the total number of frames. This does not apply to Path from File…

Integer value of 1 or greater
1= no supersampling
2 = 2x supersampling, etc…
Also, the 29 MP hexagonal images are already supersampled in (s,t) during the resampling process.

Computes, displays frame-by-frame, and saves a perspective movie in previously defined output folder.

Watch command line output for estimated wait time.

Controls the path of the perspective sweep animation.
Square = Box path in a clockwise direction about (u,v) = (0,0). *Note that without an edge buffer, this path will go off the circular aperture.*
Circle = Clockwise circular path with radius equal to the microimage radius minus any edge buffer. *Note that the circular path evaluates many non-integer (u,v) values which take slightly longer to compute than integer values as in Square or Cross.*
Cross = Moves in a cross (or plus + sign) path across the aperture plane. *Order: Left-Right-Center-Bottom-Top-Center-Left*
Path from File… = Will prompt user for a text file containing a list of [u v] coordinates upon clicking to export either a movie or GIF.
See samplePath.txt. The format is: u value <space> v value with line breaks to indicate new points.



Refocusing Settings

None: The full 15x15 or 17x17 grid of extracted image data behind each microlens is used in refocusing. (May pick up adjacent microlens data.)
Circular: A circular mask is applied such that the corners of the microimages are masked out. Circular should be selected in most cases when using a hexagonal camera array.
(This prevents picking up data from neighboring microlenses in the tightly packed hexagonal array.)

Refocusing type: **additive filtered multiplicative**

Noise threshold for filtered refocusing

Filter threshold for filtered refocusing

Enables constant magnification settings

Displays a handy quick reference figure for the relationship between the depth parameter alpha and refocused focal planes.

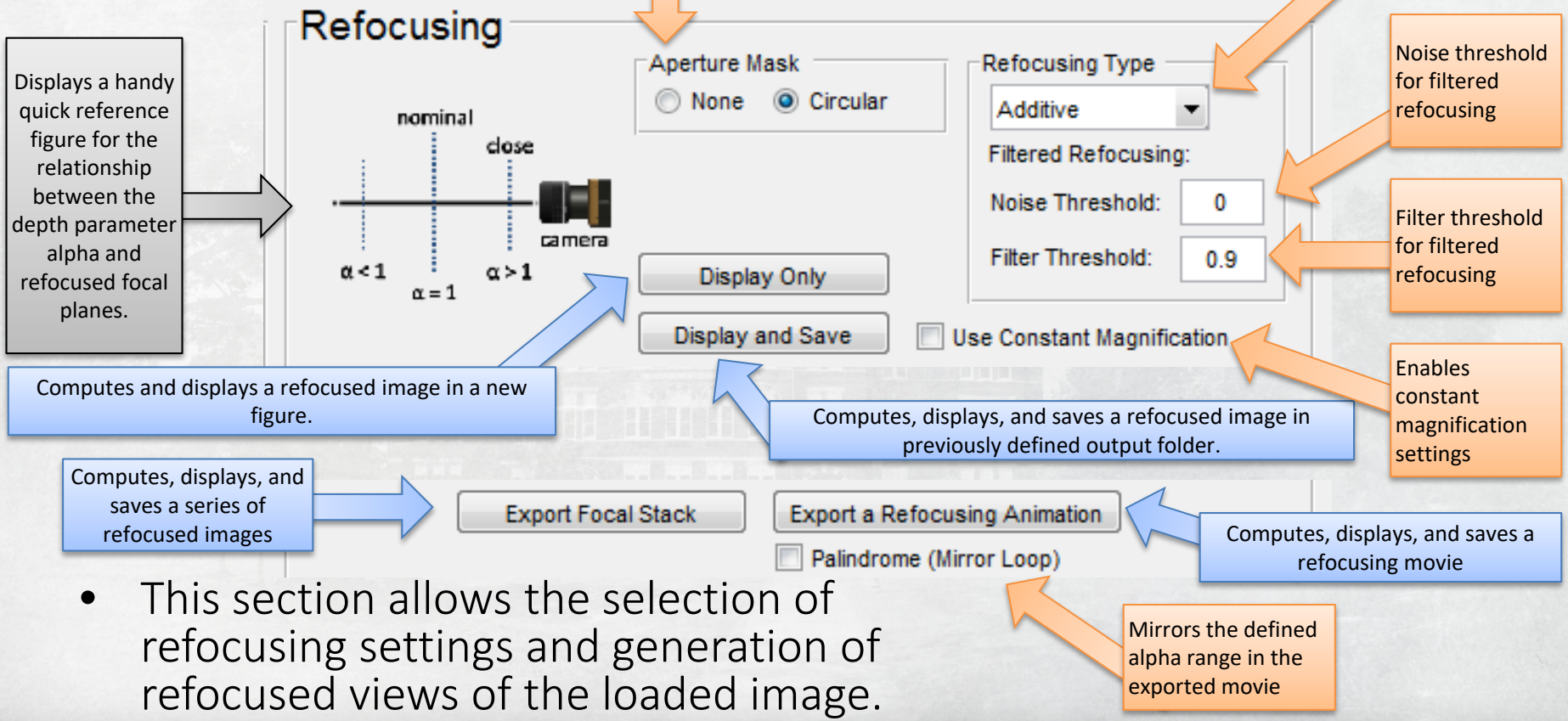
Computes and displays a refocused image in a new figure.

Computes, displays, and saves a refocused image in previously defined output folder.

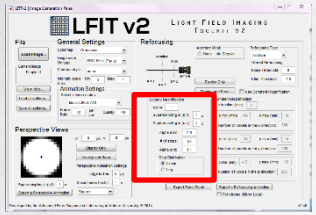
Computes, displays, and saves a series of refocused images

Computes, displays, and saves a refocusing movie

Mirrors the defined alpha range in the exported movie



- This section allows the selection of refocusing settings and generation of refocused views of the loaded image.



Legacy Refocusing

Value greater than 0
(decimal values supported)
α>1 focuses closer
α=1 focuses at nominal focal plane
α<1 focuses further

Legacy Magnification
alpha: 1
Supersampling in (s,t): 1 x
Supersampling in (u,v): 1 x
Alpha start: 0.9
# of steps: 20
Alpha end: 1.1
Step Distribution
Linear
Log

Integer value of 1 or greater
1= no supersampling
2 = 2x supersampling
4 = 4x supersampling, etc…
NOTE: (s,t) supersampling increases resolution. (u,v) supersampling significantly increases processing time.

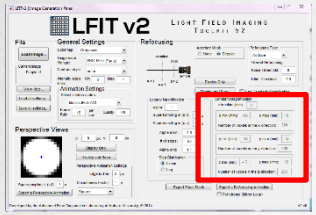
Also, the 29 MP hexagonal images are already supersampled in (s,t) during the resampling process.

Linear = Linearly spaced values of alpha.

Log = Slightly increases the number of alpha values below 1 and decreases the number of alpha values present above 1 via log spacing.
Follows formula:
=logspace(log10(alphaStart),log10(alphaEnd),steps)

Integer number of slices in stack

- This section allows for the selection of standard refocusing settings



Constant Magnification Refocusing

z-location for single image display/save)

Constant Magnification

z location (mm): 0

x min (mm): -18 x max (mm): 18

Number of voxels in the x-direction: 300

y min (mm): -12 y max (mm): 12

Number of voxels in the y-direction: 200

z min (mm): -12 z max (mm): 12

Number of voxels in the z-direction: 200

minimum and maximum x values in the volume

number of voxels in the x direction

similarly for y and z values

- This section allows for the selection of constant magnification refocusing settings.

For processing entire folders of data in an automated fashion

BATCH MODE

Batch Mode

- To automate LFIT, a batch mode setting can be enabled in the initial interface panel.
- LFIT will automatically process every raw plenoptic image in the designated folder according to the batch mode portion of the main program script.
- Open the main program file and save it under a new name.
  - Use the original as a template, and save it under different names as needed when making new batch processing section edits.
- If the functionalities available are not sufficient for a particular processing requirement, the individual functions may also be used independently for additional customization.

Batch Mode

```
%%%%%%%%------------------------------------%%%%%%%%
%%%%%%%%---USER EDITS BEGIN BELOW HERE---%%%%%%%%
%%%%%%%%------------------------------------%%%%%%%%
```

- Scroll down in the file until the above section is found at line 109
- Between the above and the below are examples of creation of refocused and perspective shifted images as well as an example of the use of request vectors from previous versions of LFIT (request vectors are not recommended)
- By editing the query vectors and removing unneeded generation functions, the user can create a custom batch processing script.

```
%%%%%%%%------------------------------------%%%%%%%%
%%%%%%%%---USER EDITS END ABOVE HERE---%%%%%%%%
%%%%%%%%------------------------------------%%%%%%%%
```

- The following slides provide descriptions of the query parameters
- If query parameters are not selected, the defaults in lfiQuery.m are used

Batch Mode – General Settings

Parameter	Description
uvFactor	(u,v) supersampling factor: 1 is none, 2 = 2x SS, 4 = 4x SS, etc
stFactor	(s,t) supersampling factor: 1 is none, 2 = 2x SS, 4 = 4x SS, etc
contrast	contrast stretching style: false, 'none', 'slice', 'stack'
intensity	imadjust limits
mask	aperture masking of microlenses: false, 'circ'

Batch Mode – Output Settings

Parameter	Description
saveas	output image format: false, 'bmp', 'png', 'jpg', 'png16', 'tif16', 'gif', 'avi', 'mp4'
quality	output quality, only applies to JPG, AVI, and MP4
codec	output codec, only applies to AVI and MP4
framerate	output framerate, only applies to GIF, AVI, and MP4
display	image display speed: false, 'slow', 'fast'
colormap	the colormap used in displaying the image, e.g. 'jet' or 'gray'
background	background color of the figure if the title is enabled, e.g. [.8 .8 .8] or [1 1 1]
title	title flag: FALSE for no caption, 'caption' for caption string only, 'annotation' for alpha/uv value only, 'both' for caption string + alpha/uv value
caption	caption string is the string used in the title for title flag of 'caption' or 'both'
grouping	directory grouping: 'image' to save on a per-image basis or 'alpha' to save on a per-alpha basis

Batch Mode – Refocus/Perspective Settings

Refocus Settings

Parameter	Description
fMethod	focus-adjust method: 'add', 'mult', 'filt'
fFilter	filter parameters (does nothing if METHOD isn't 'filt') 1. threshold below which intensity will be disregarded as noise 2. filter intensity threshold
fZoom	zoom type: 'legacy', 'telecentric'
fAlpha	alpha value(s) used in legacy focus-adjust: a=1 nominal focal plane, a<1 focuses further away, a>1 focuses closer to the camera
fPlane	z-plane(s) used in telecentric focus-adjust
fGridX	(x,y) grid x-axis
fGridY	(x,y) grid y-axis
fLength	main lens focal length
fMag	nominal magnification

Perspective Settings

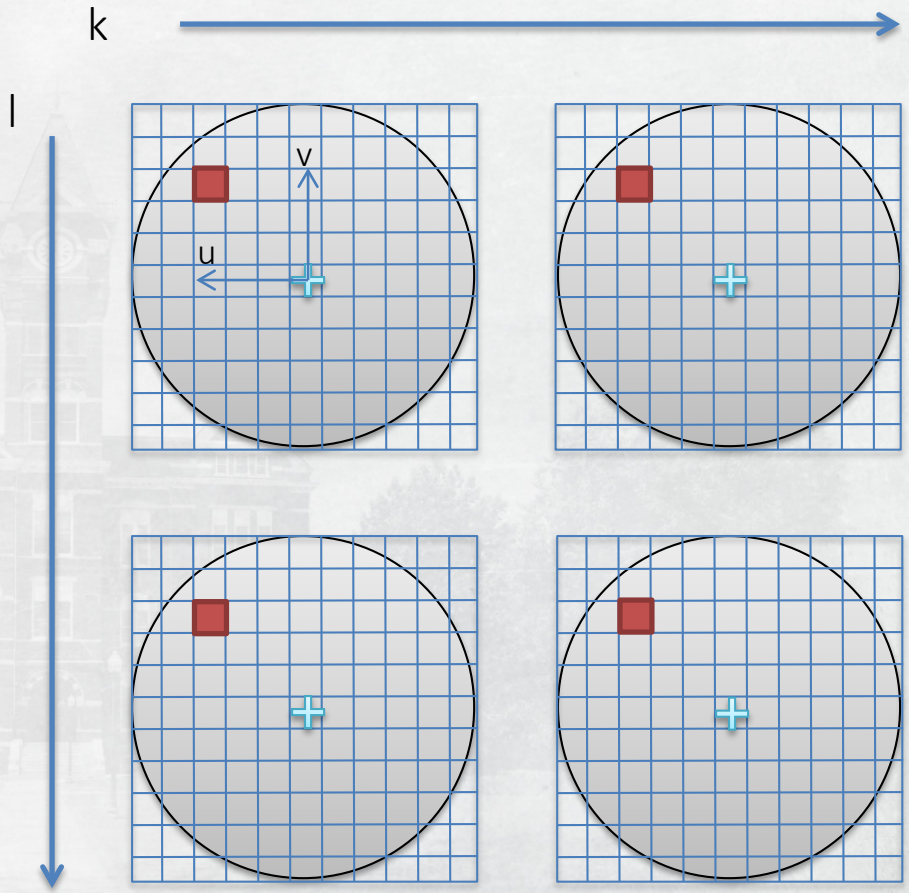
Parameter	Description
pUV	(u,v) position(s) for which to generate a perspective view; non-integer values ARE supported

Other relevant LFIT materials

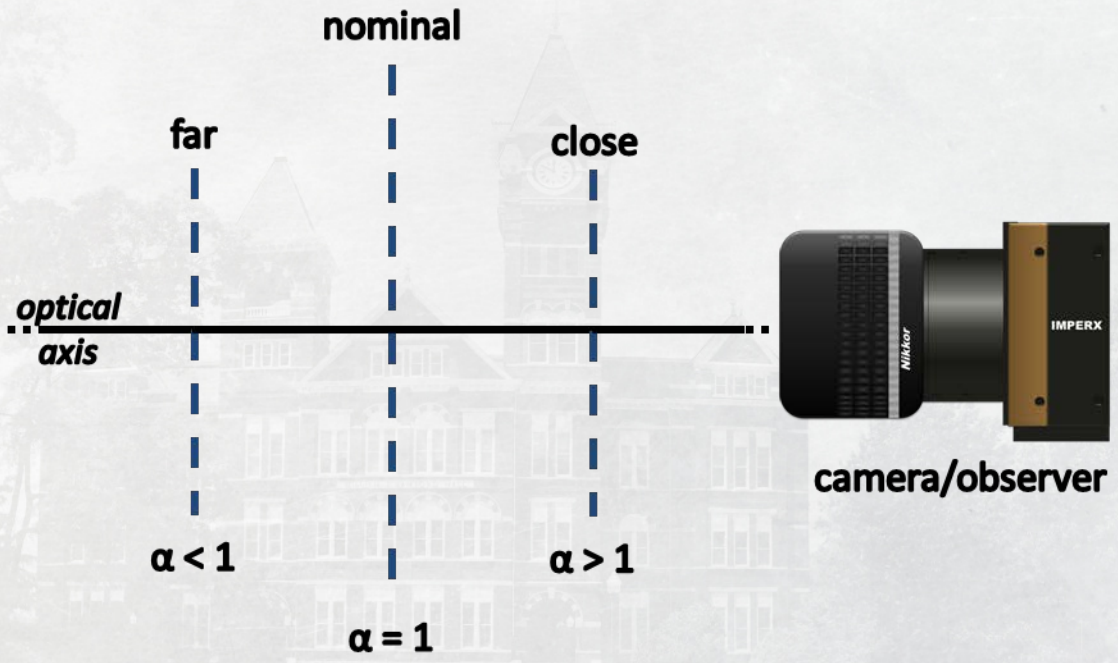
APPENDIX

Perspective Shifts

- Sub-aperture imaging
  - Hold (v,u) constant and vary (k, l) values
  - Analogous to extracting the same pixel beneath each microlens



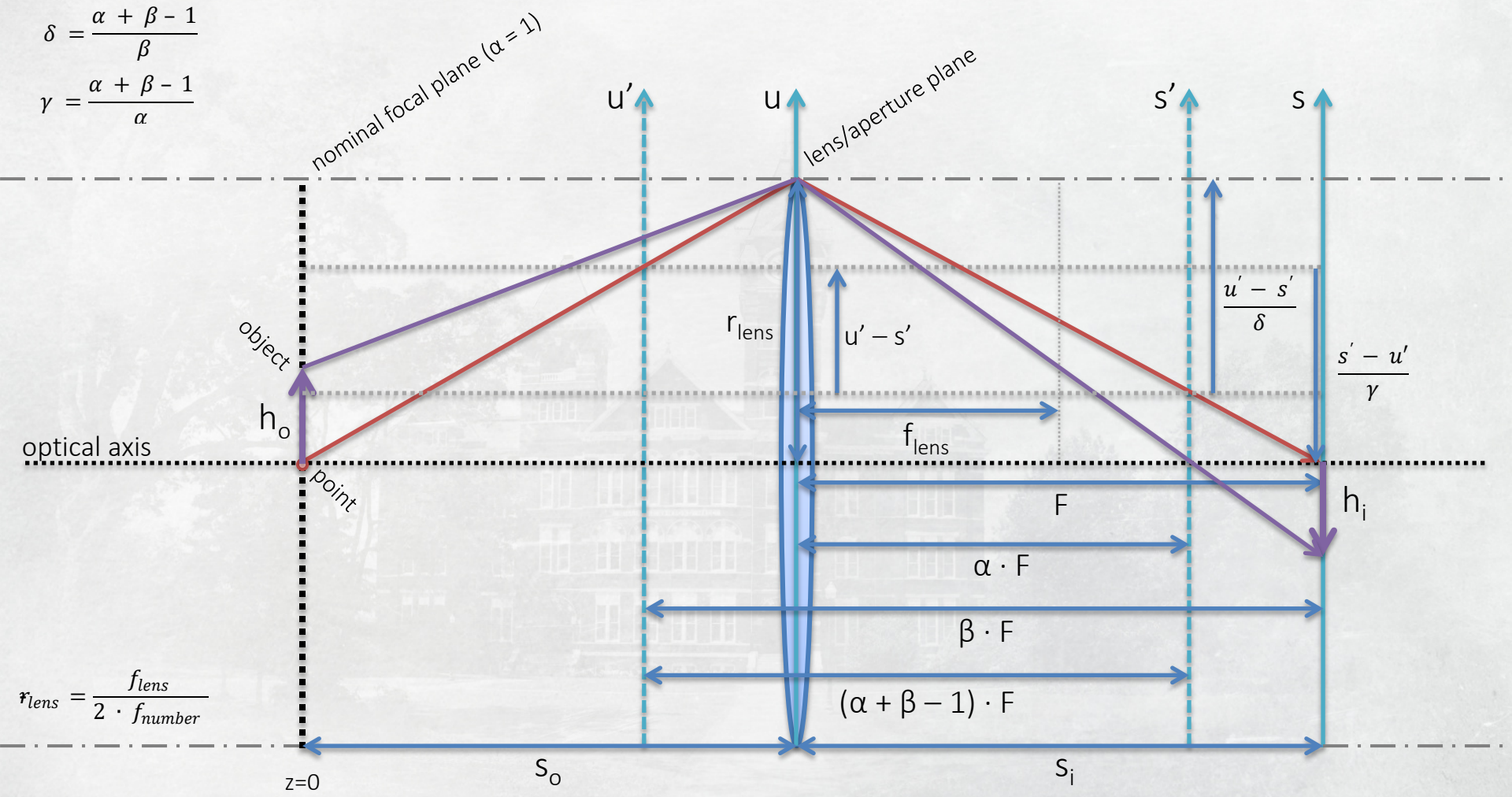
Alpha: Depth Parameter



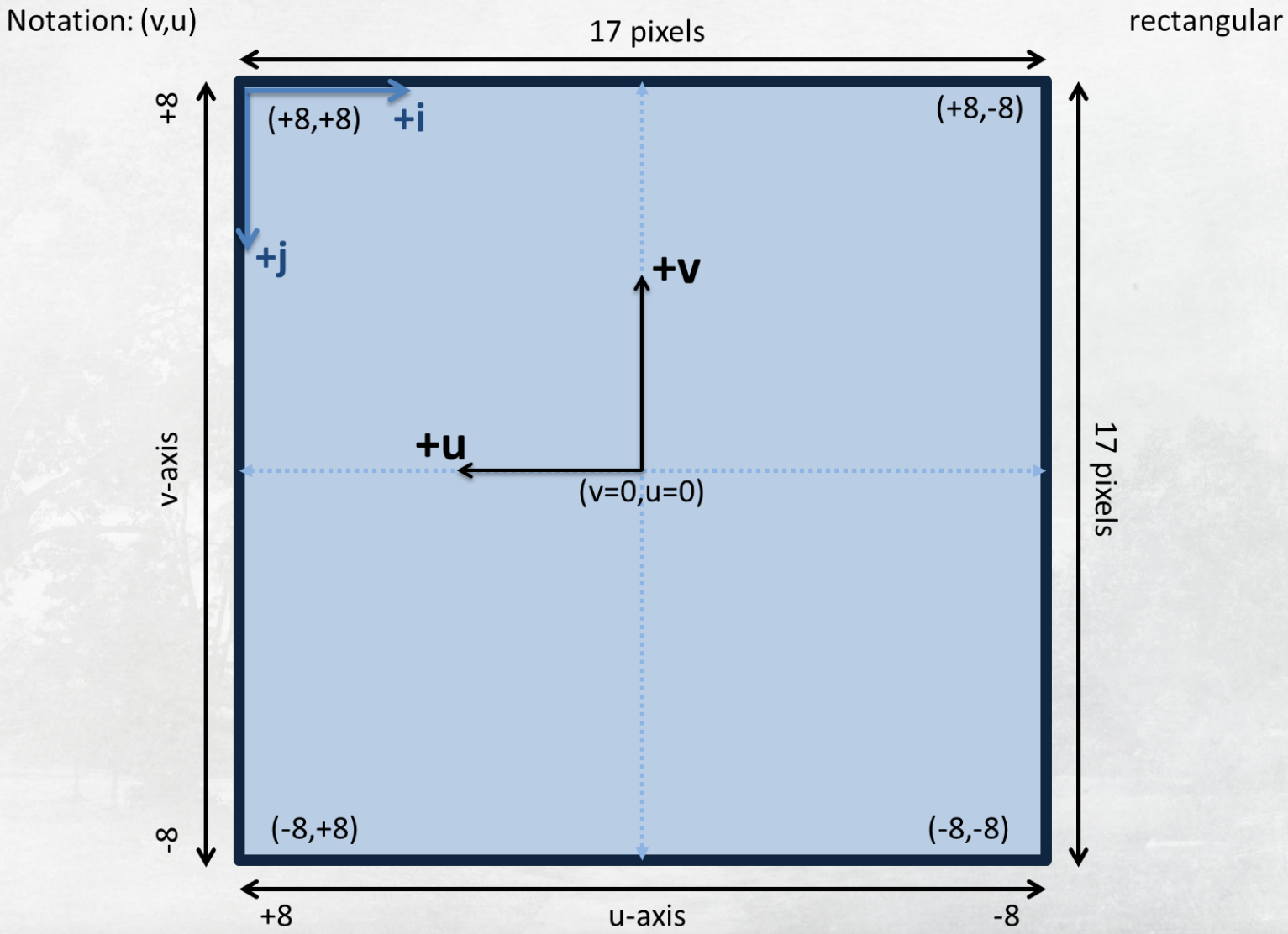
Geometric Relationships

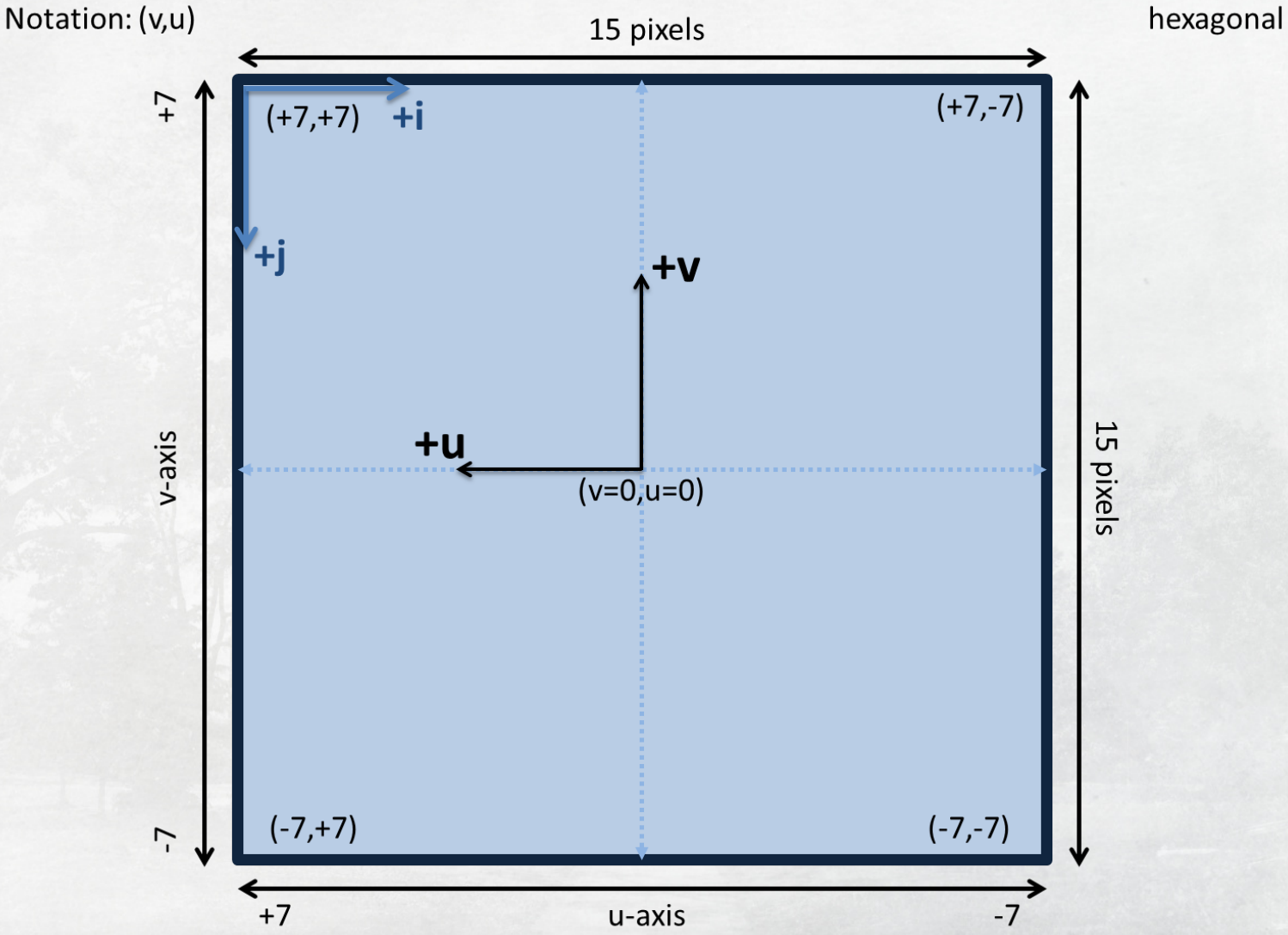
$$\delta = \frac{\alpha + \beta - 1}{\beta}$$

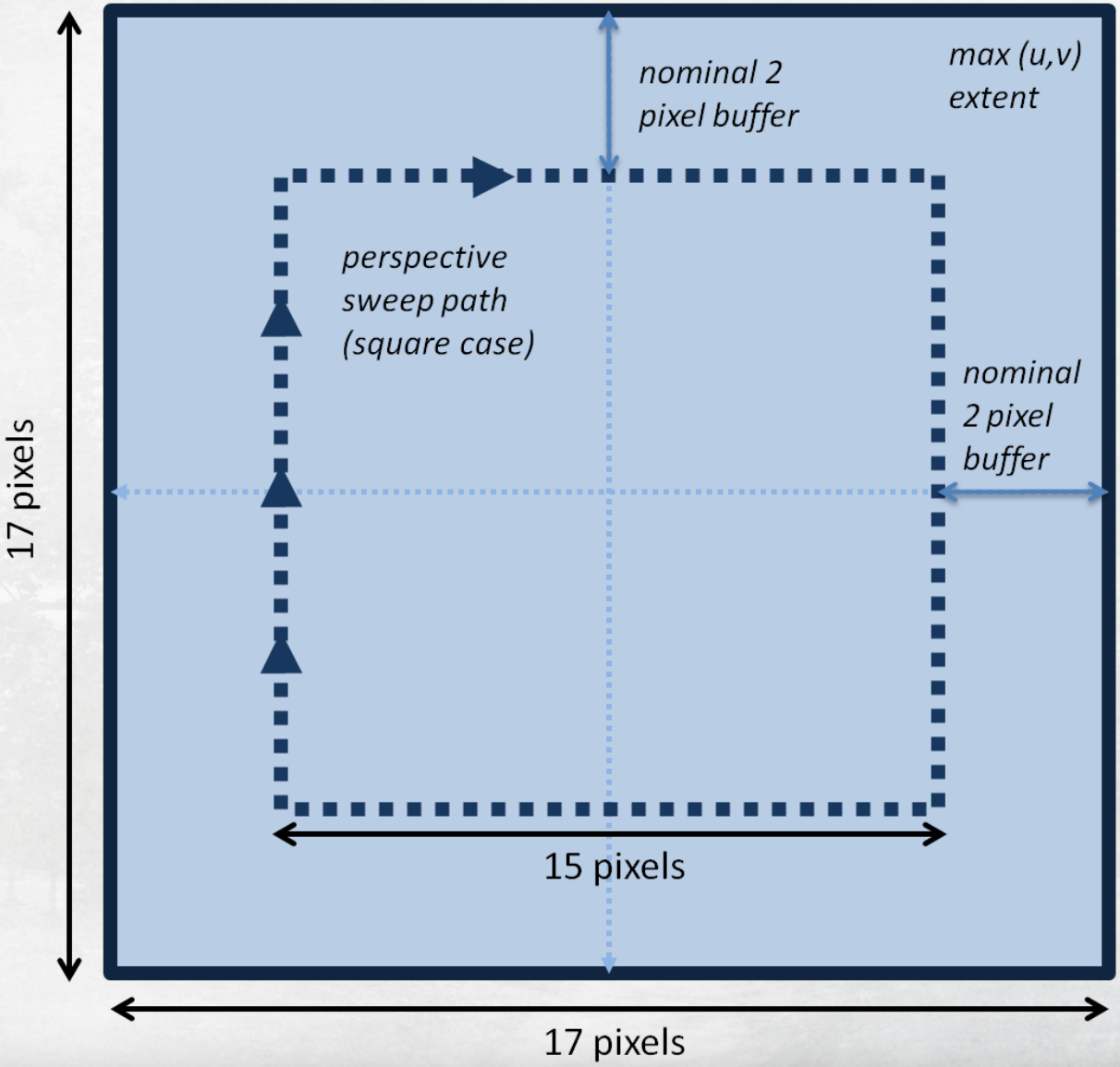
$$\gamma = \frac{\alpha + \beta - 1}{\alpha}$$

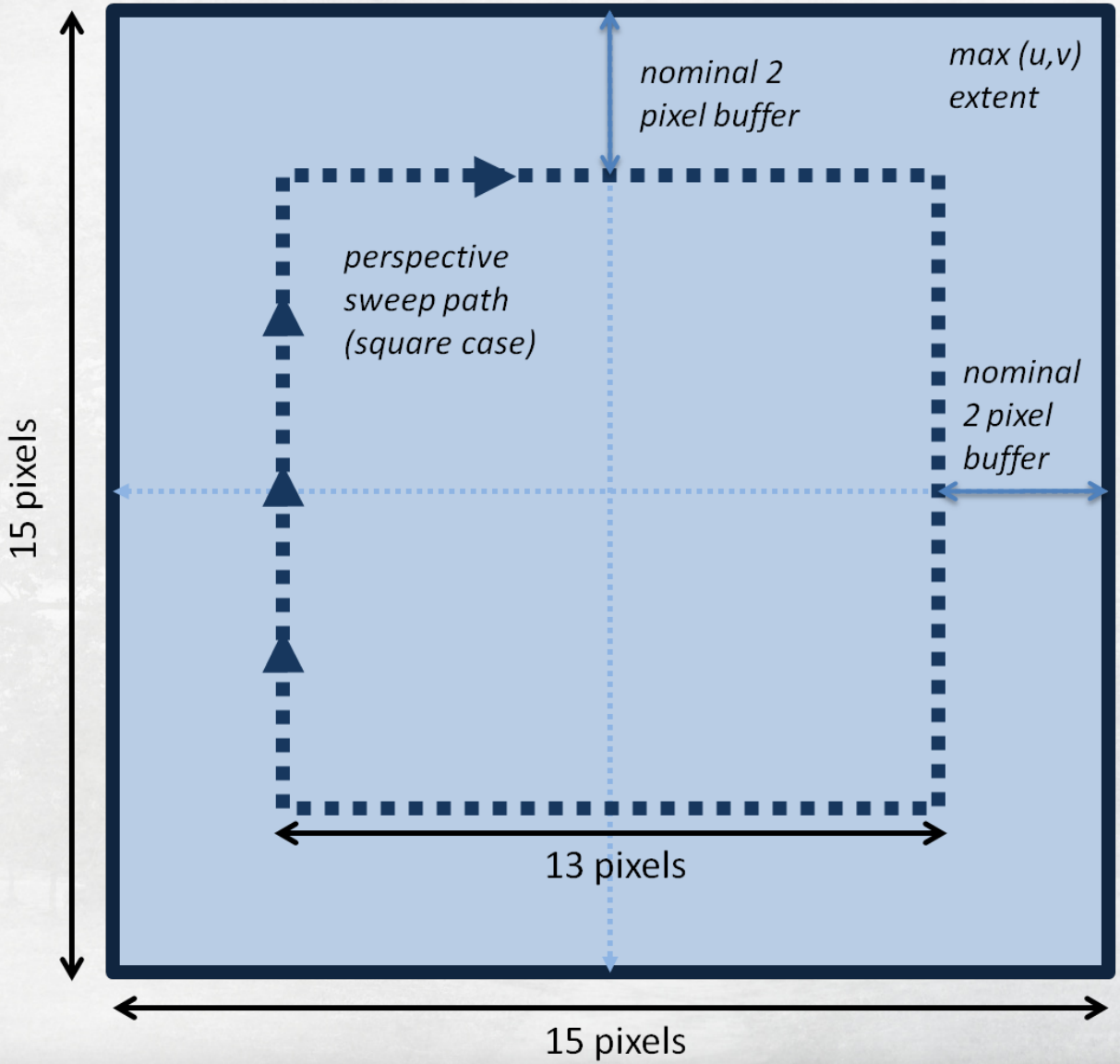


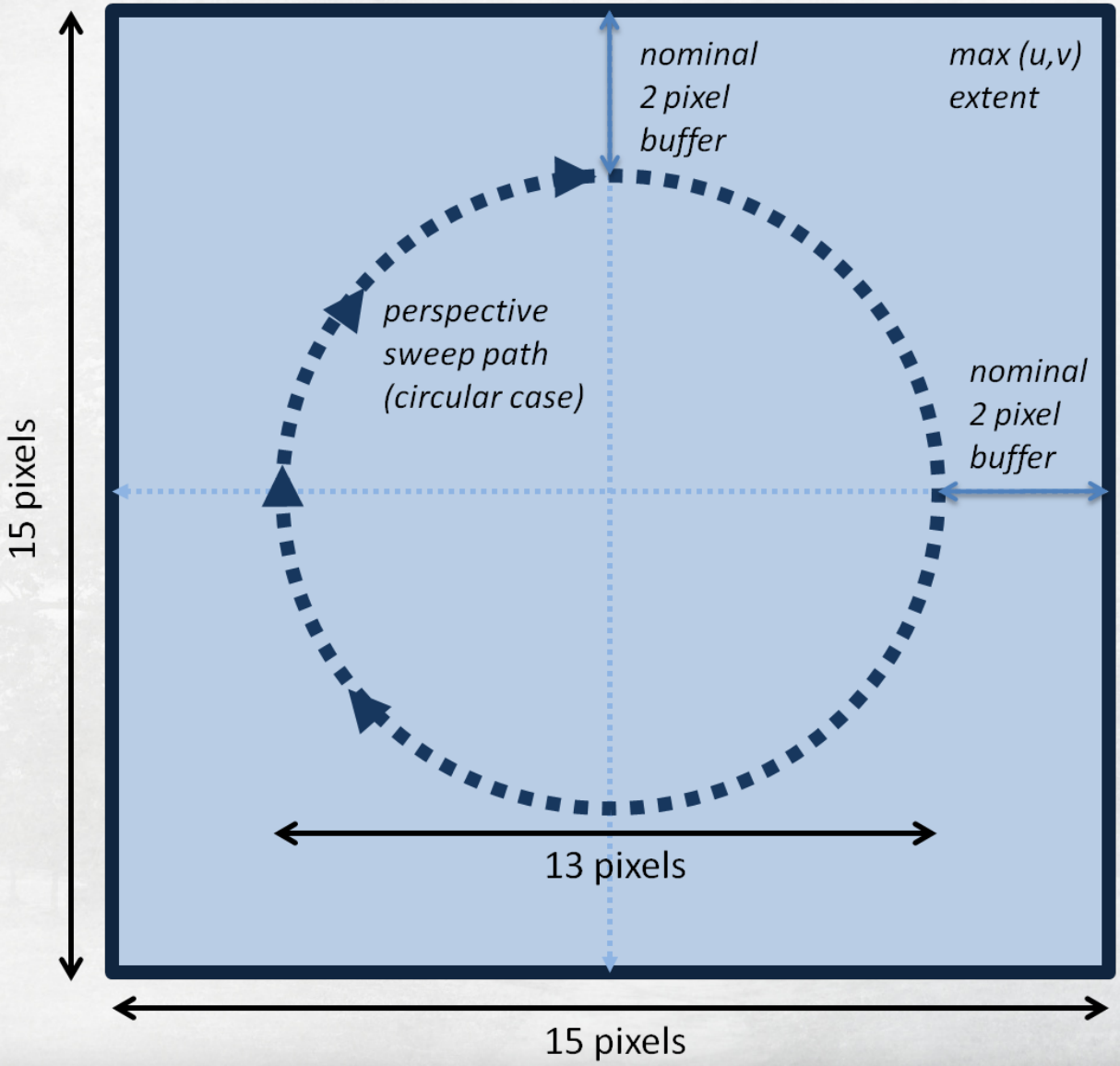
$$r_{lens} = \frac{f_{lens}}{2 \cdot f_{number}}$$

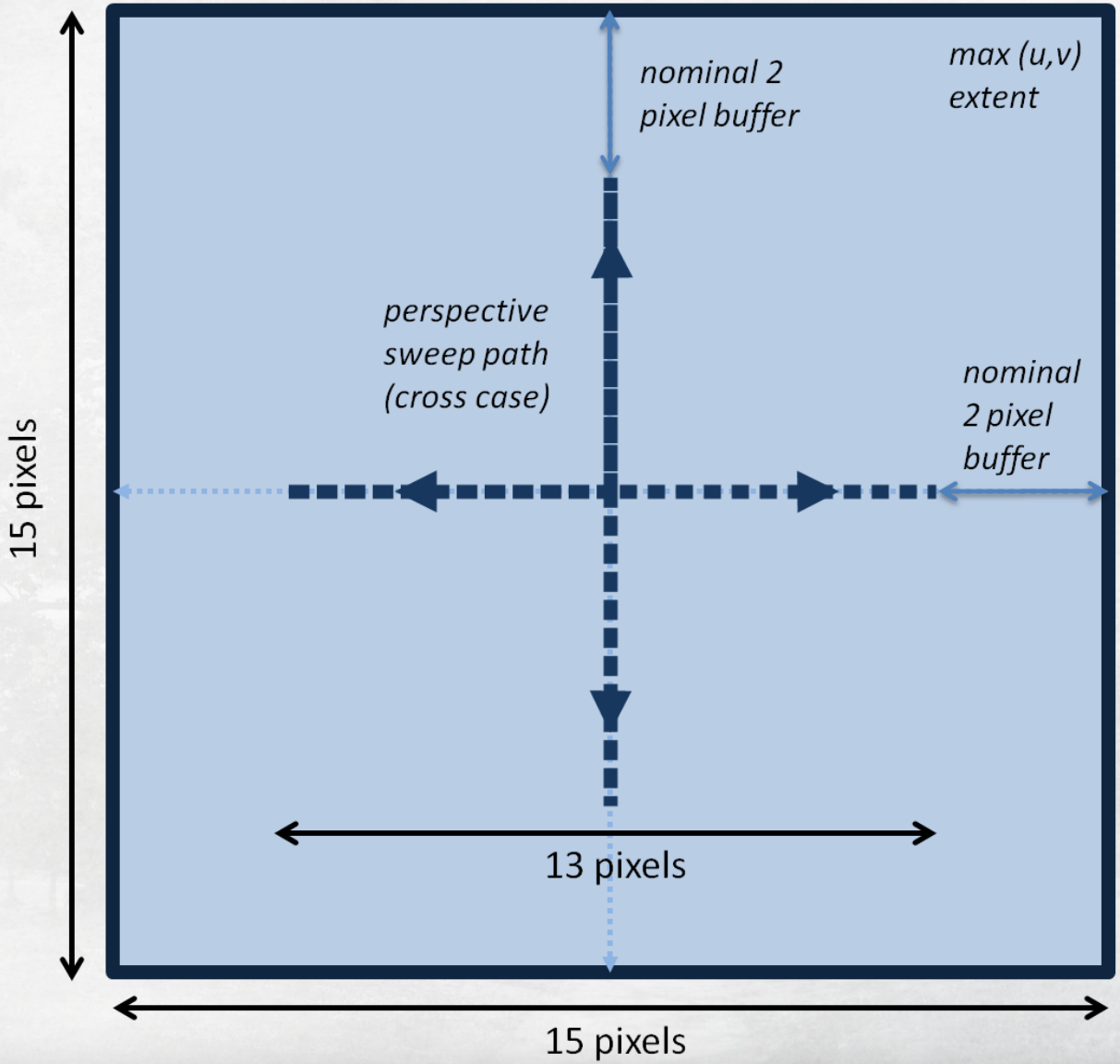

Notation: (v,u)
17 pixels
rectangular
+8
(+8,+8)
+i
(+8,-8)
+j
+v
+u
(v=0,u=0)
v-axis
17 pixels
-8
(-8,+8)
(-8,-8)
+8
u-axis
-8

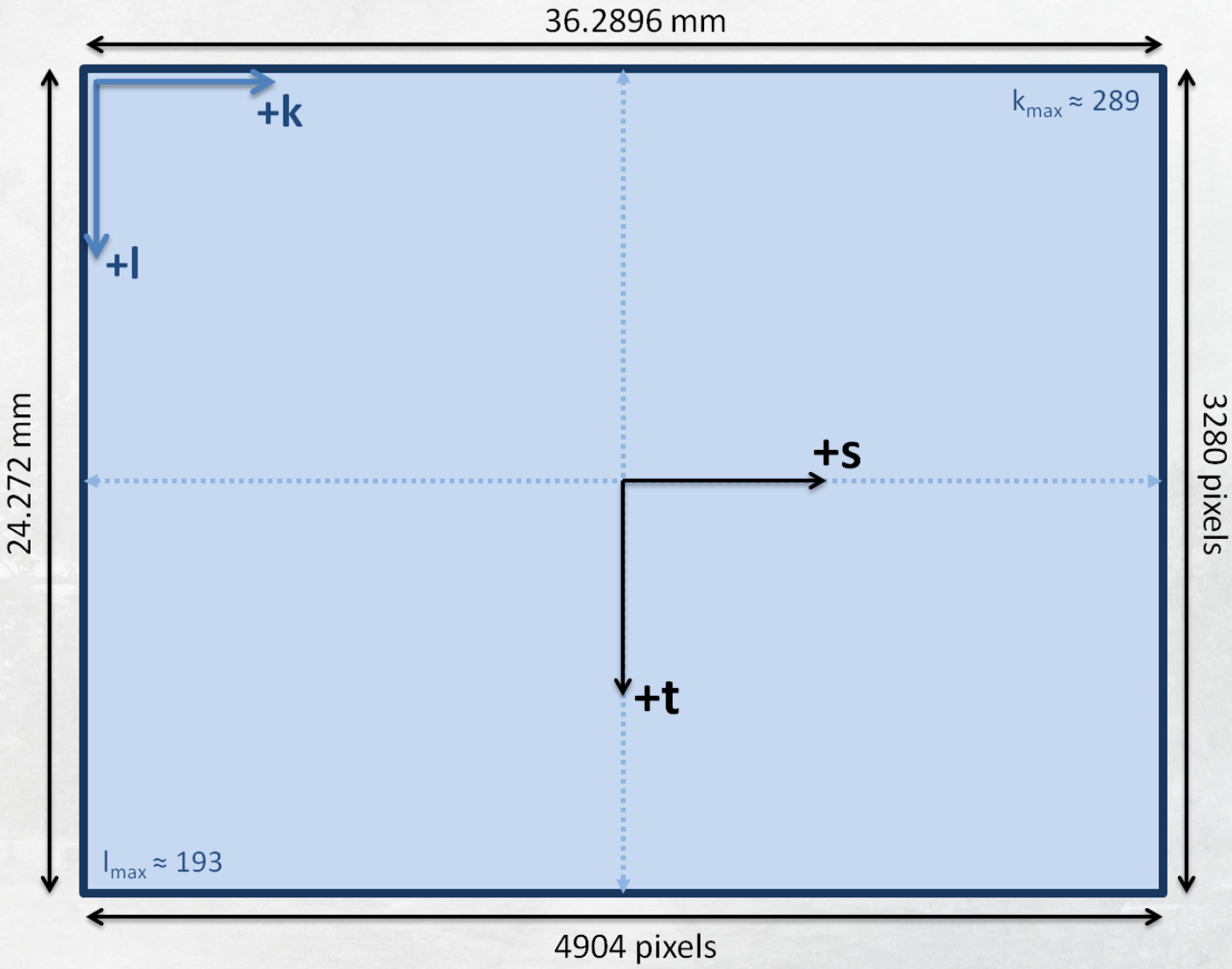

Notation: (v,u)
15 pixels
hexagonal
+7
(+7,+7)
+i
(+7,-7)
+j
+v
+u
v-axis
(v=0,u=0)
15 pixels
-7
(-7,+7)
(-7,-7)
+7
u-axis
-7

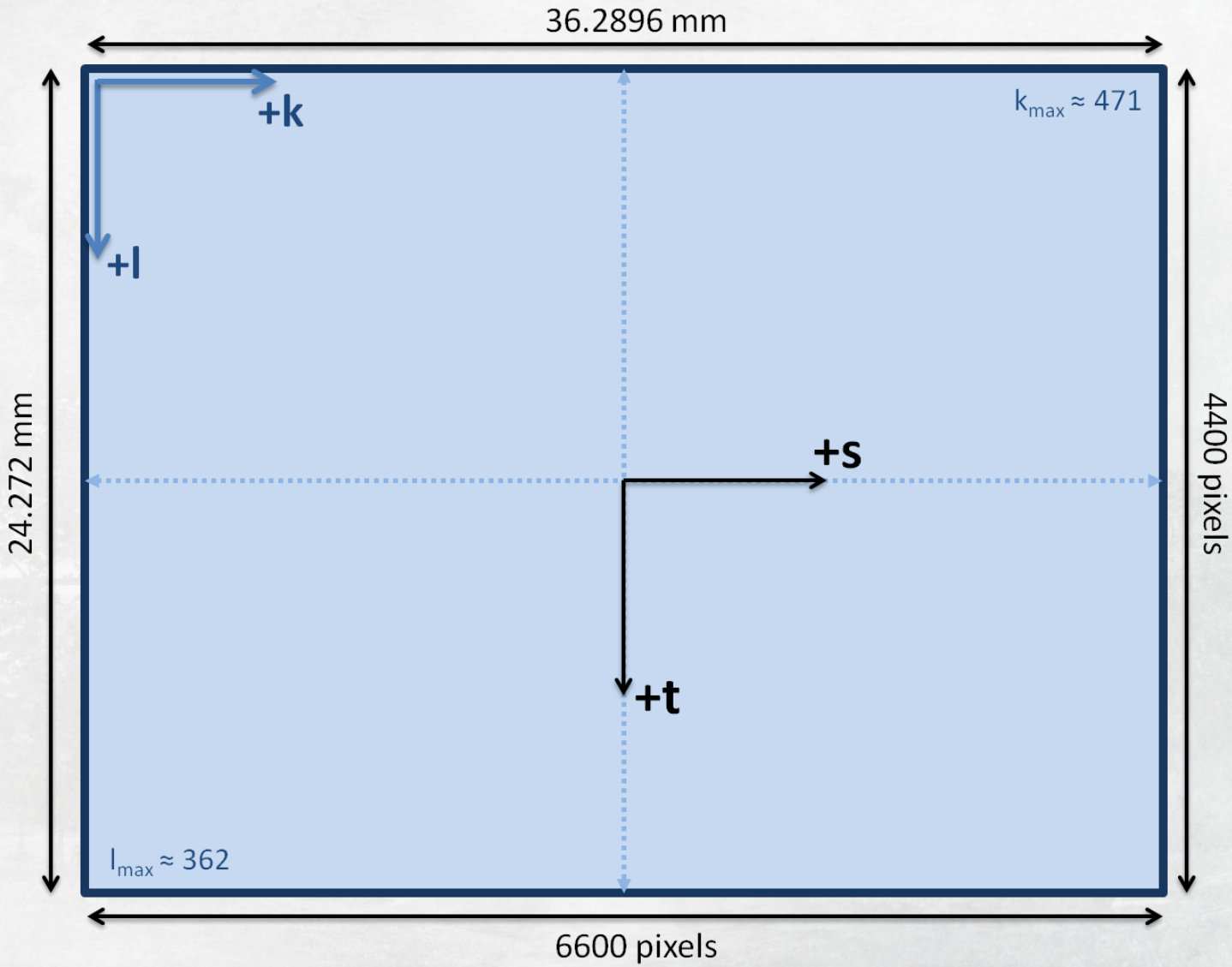

nominal 2
pixel buffer
max (u,v)
extent
perspective
sweep path
(square case)
nominal
2 pixel
buffer
17 pixels
15 pixels
17 pixels


nominal 2
pixel buffer
max (u,v)
extent
perspective
sweep path
(square case)
nominal
2 pixel
buffer
15 pixels
13 pixels
15 pixels


nominal
2 pixel
buffer
max (u,v)
extent
perspective
sweep path
(circular case)
nominal
2 pixel
buffer
15 pixels
13 pixels
15 pixels

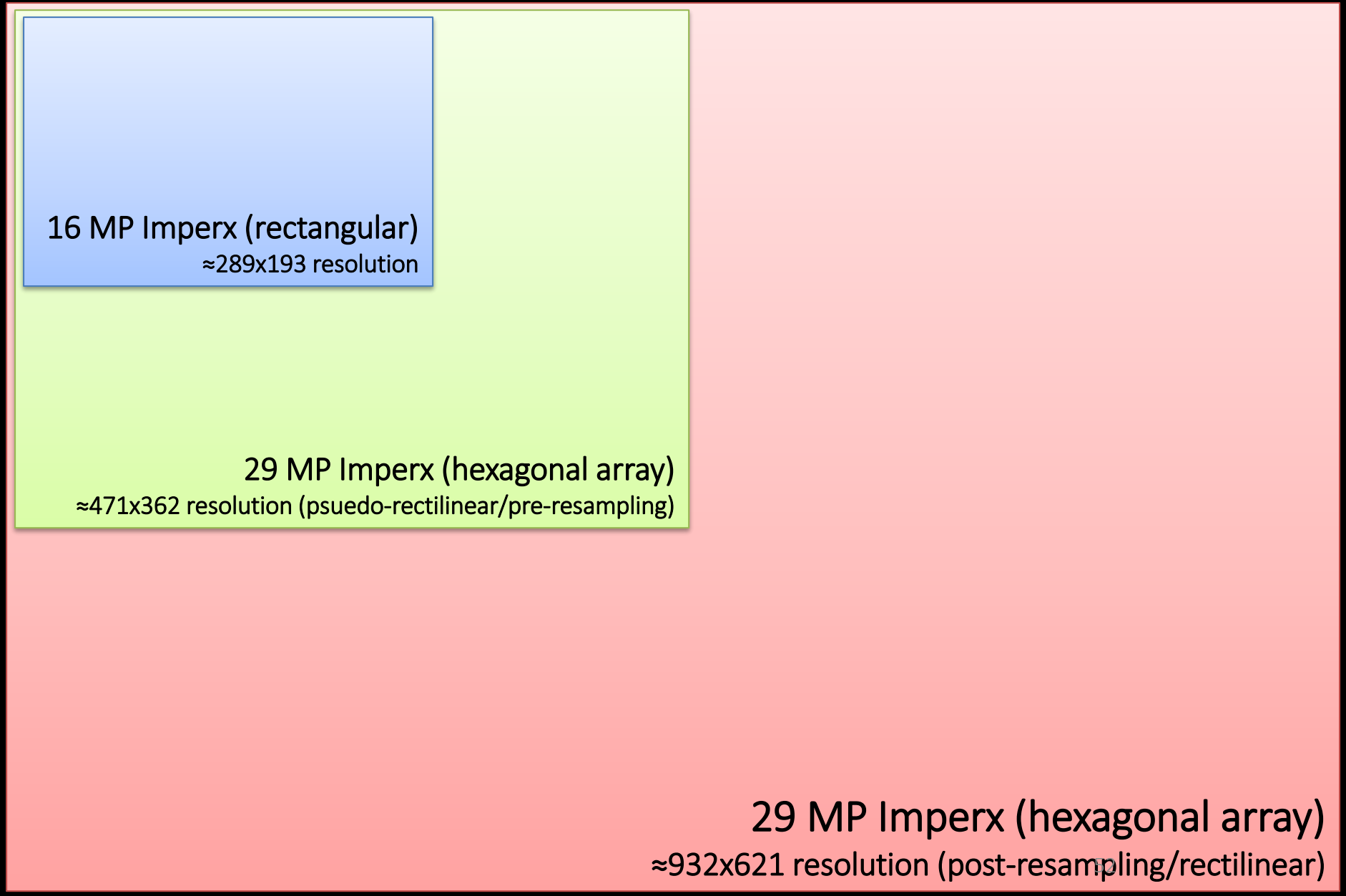

nominal 2
pixel buffer
max (u,v)
extent
perspective
sweep path
(cross case)
nominal
2 pixel
buffer
15 pixels
13 pixels
15 pixels

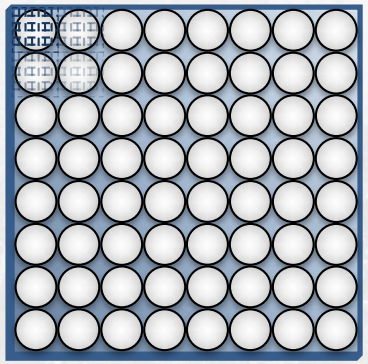

36.2896 mm
+k
+l
$k_{max} \approx 289$
+s
+t
$l_{max} \approx 193$
24.272 mm
3280 pixels
4904 pixels



l_{max} and k_{max} here are pre-resampling.

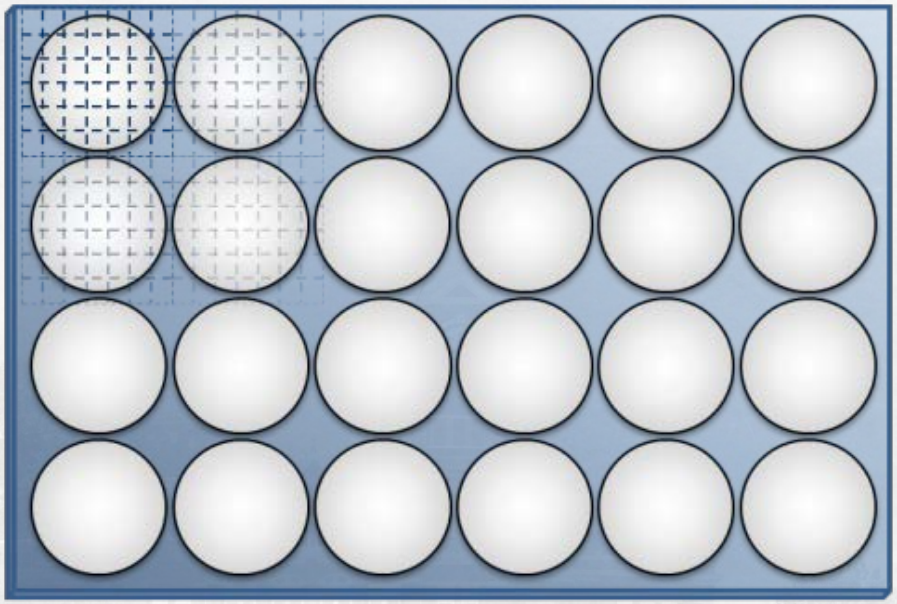
1:1 Resolution Comparison





LFIT v2

Light Field Imaging Toolkit V2



LFIT v2

LIGHT FIELD IMAGING TOOLKIT V2


AFDL
advanced
flow
diagnostics
laboratory