Augmented Reality on FPGA

Realtime Object Recognition and Image Processing

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6.111 Fall 2011

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Introduction

- Overlay a digital image on a physical object in realtime.
- In this case, we want to identify a picture frame in captured video, and output video with another image distorted to fit on top of the picture frame.

Example Image

Example Image

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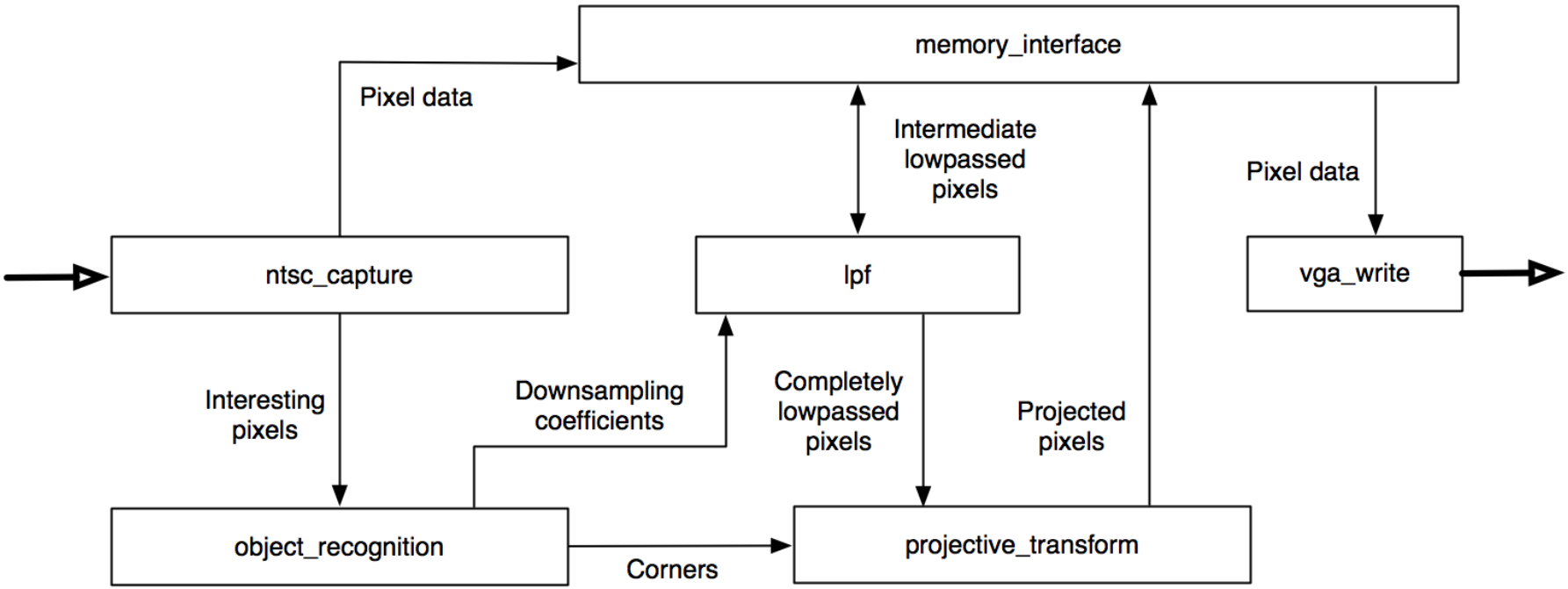
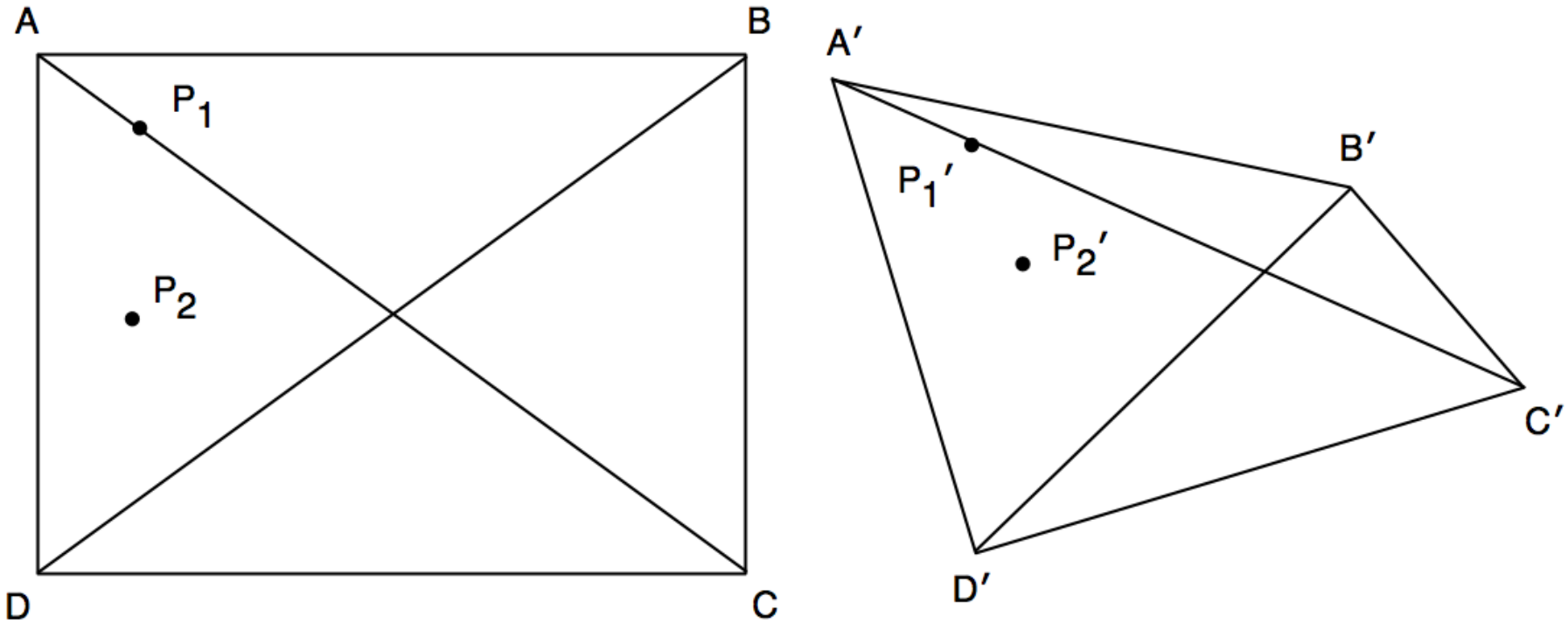
Top-Level Overview

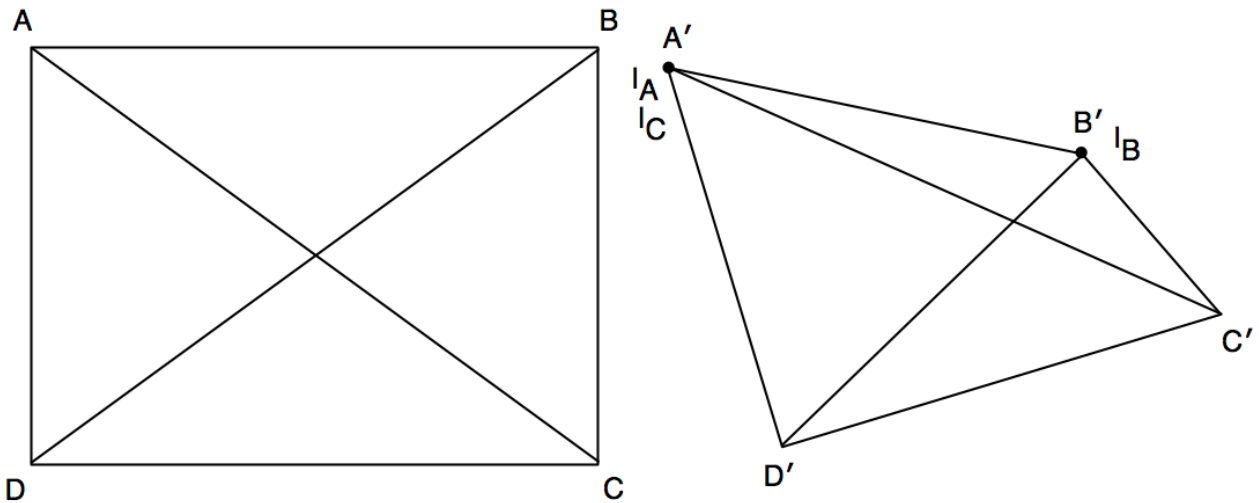


projective_transform: Purpose



- Skew to any arbitrary convex quadrilateral

`projective_transform`: How the algorithm works



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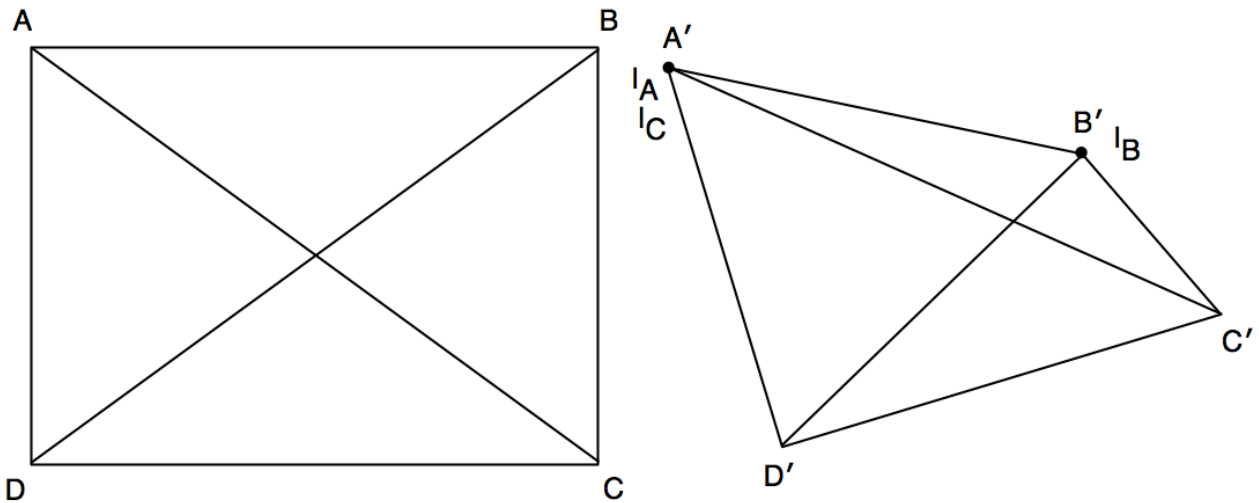

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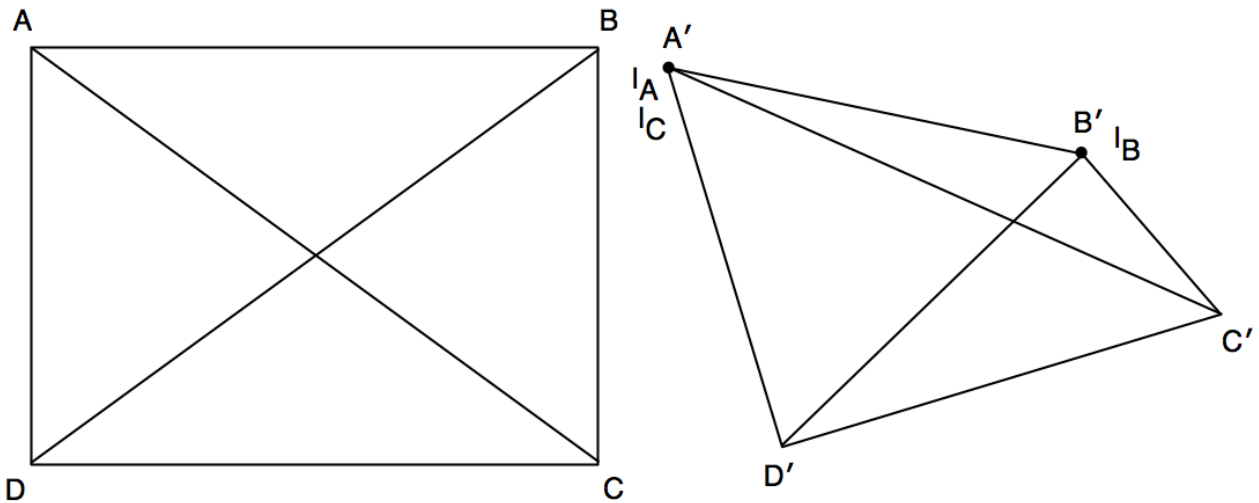

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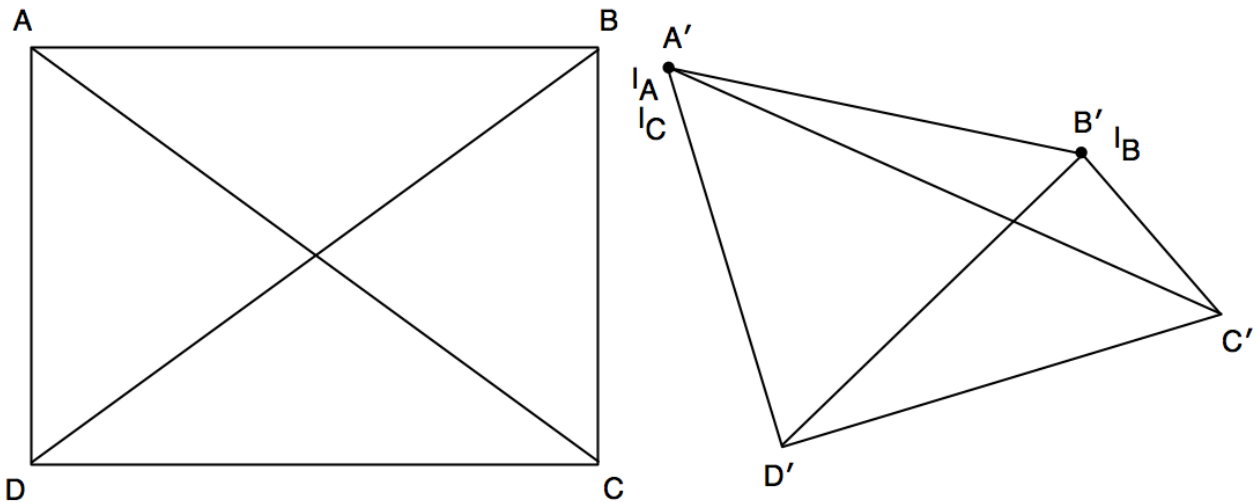

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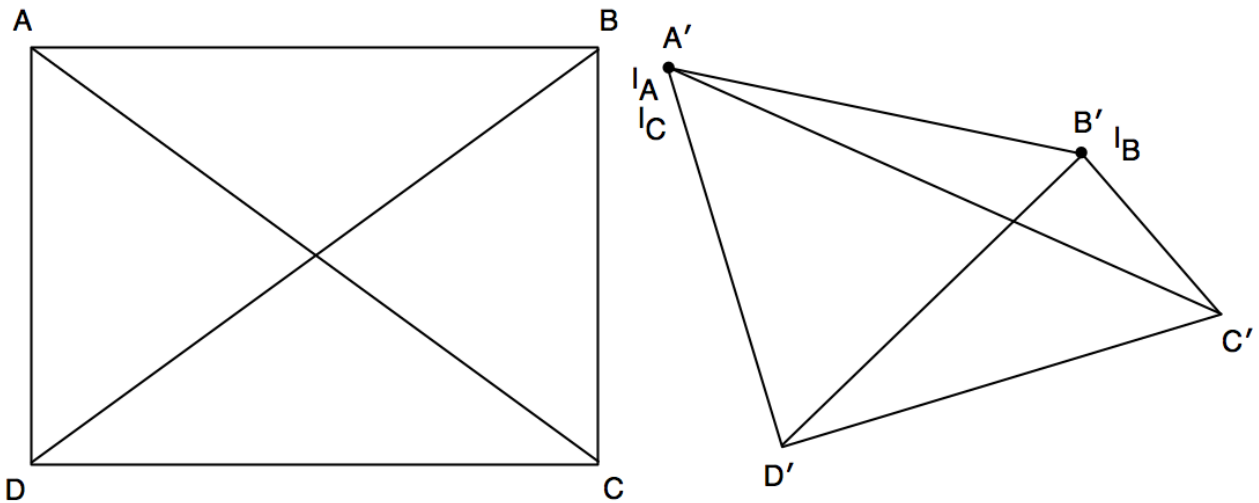

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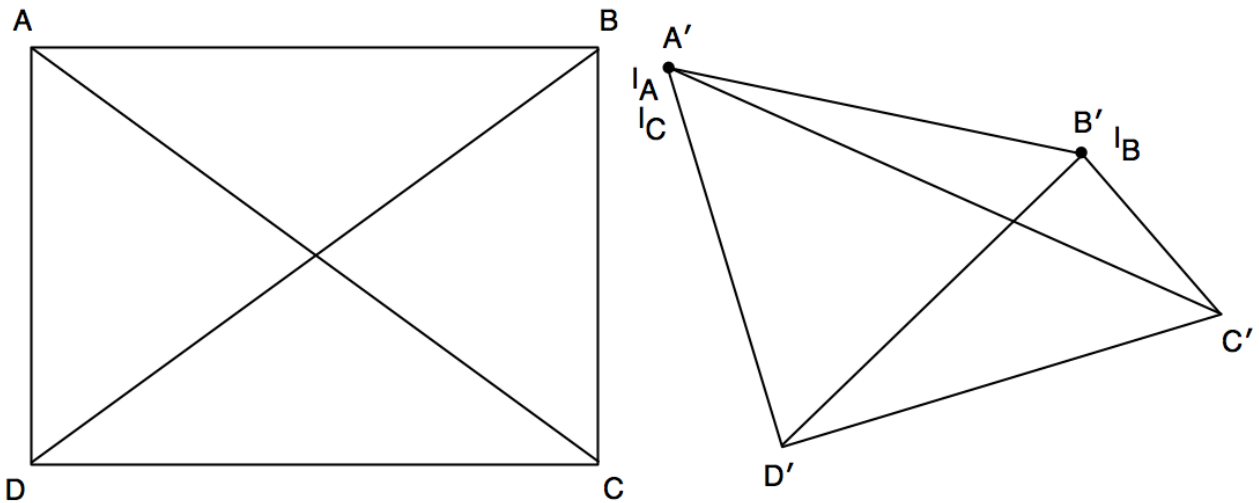

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6. Create a third iterator point, I_C at the location I_A.

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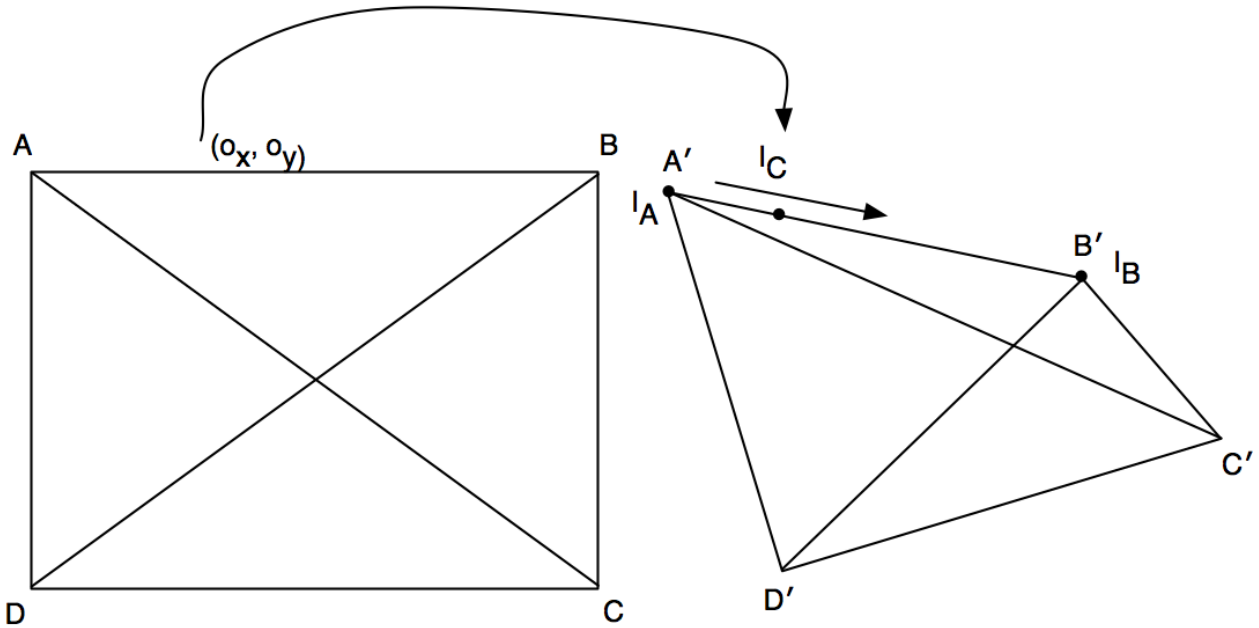

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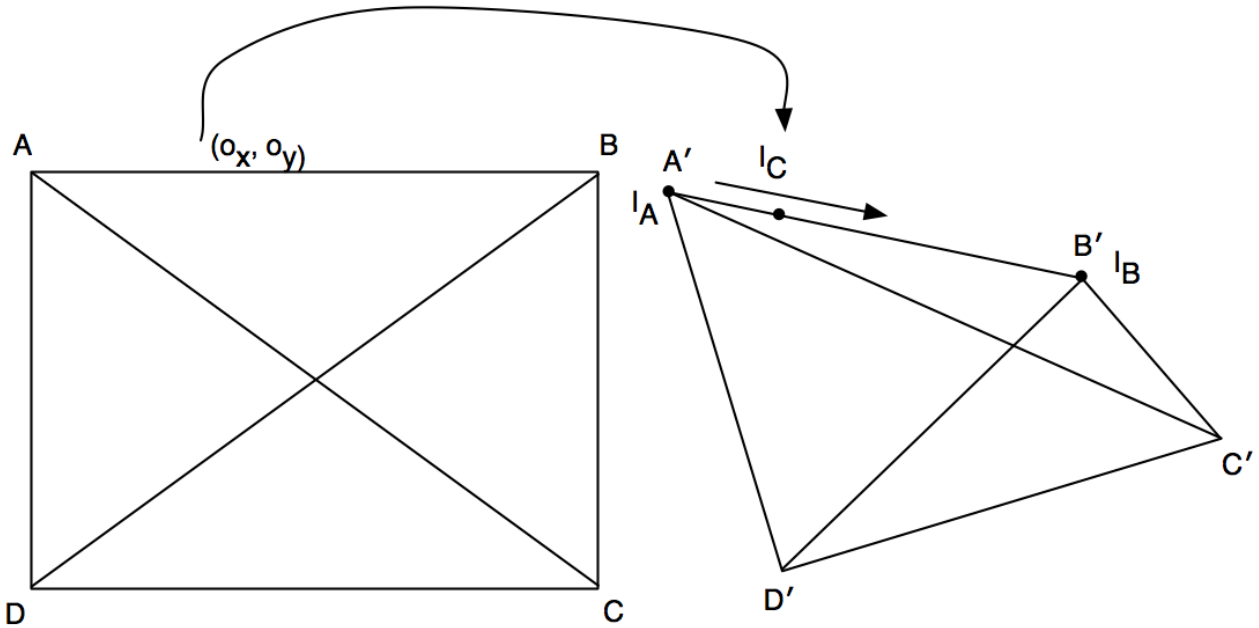

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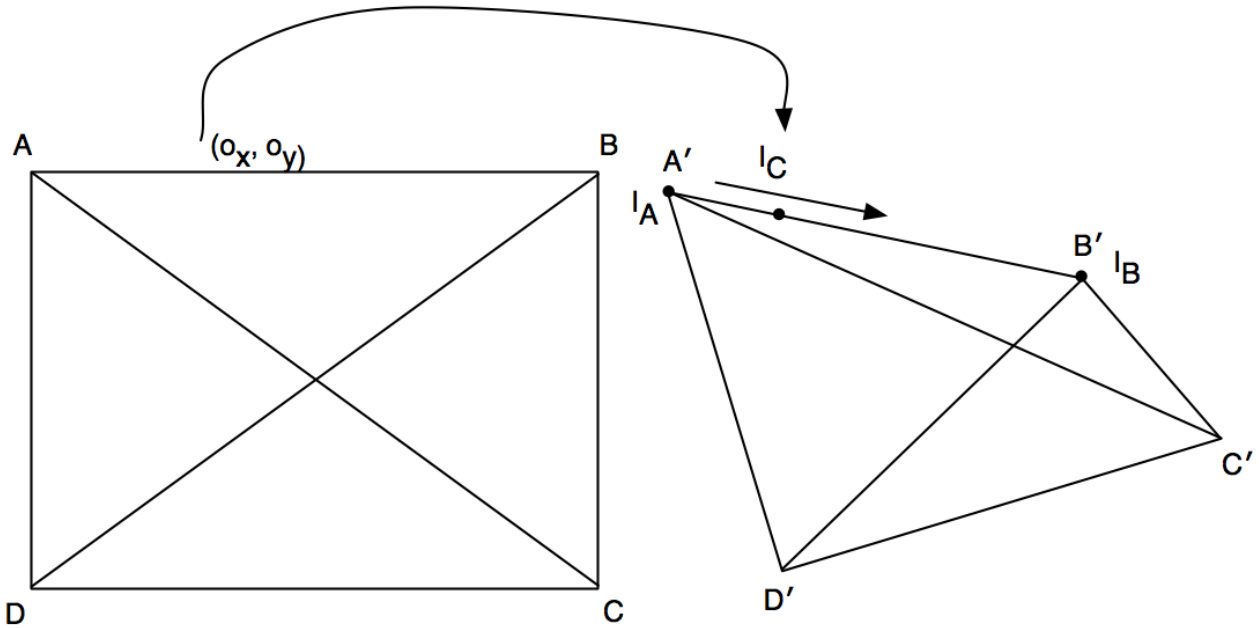

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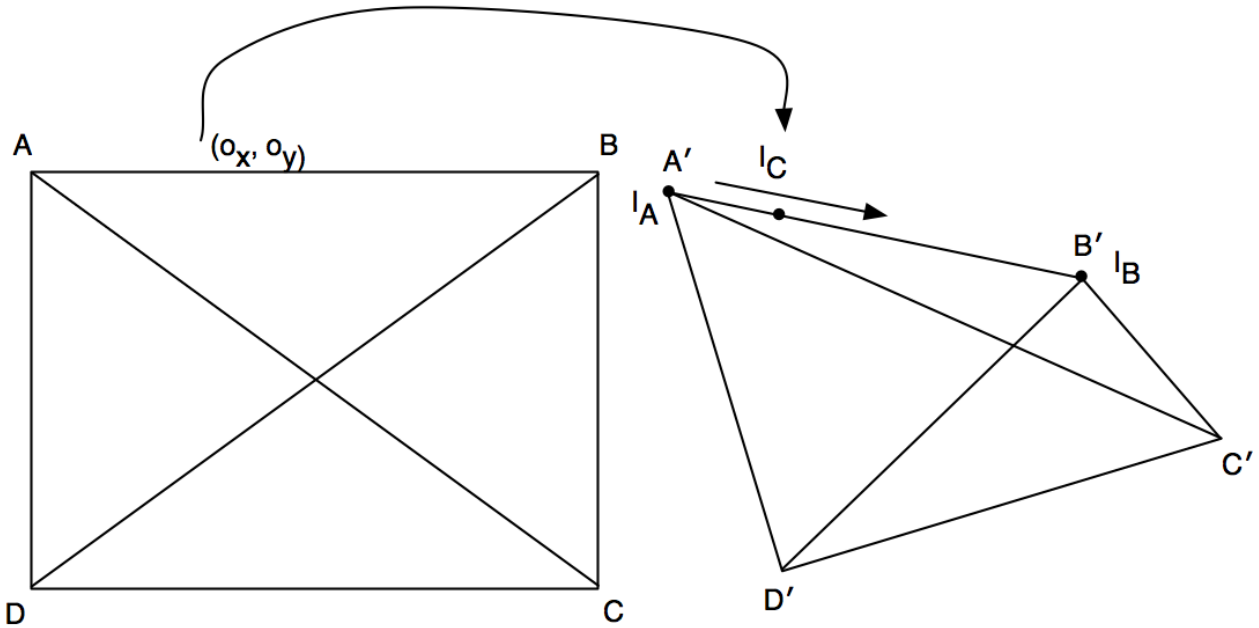

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10. Repeat steps 7–9 until $I_C = I_B$.

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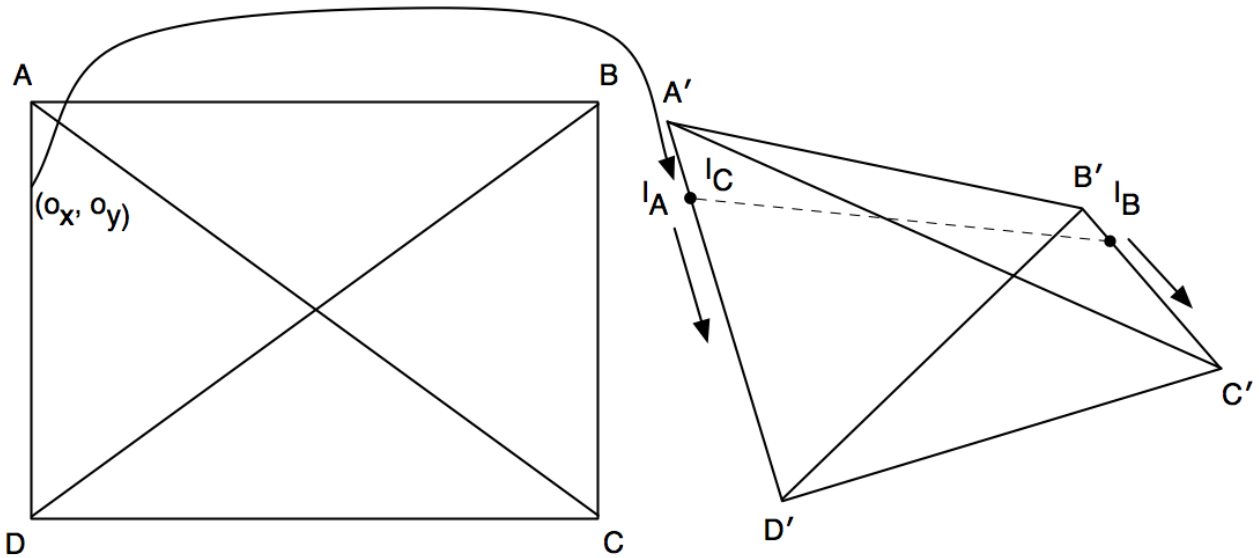

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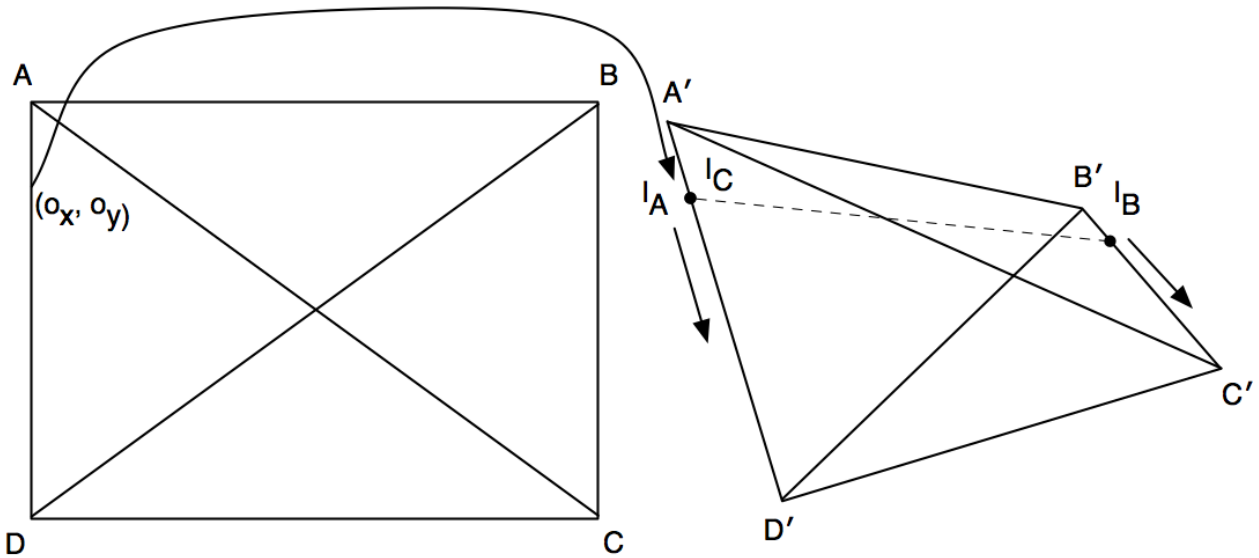

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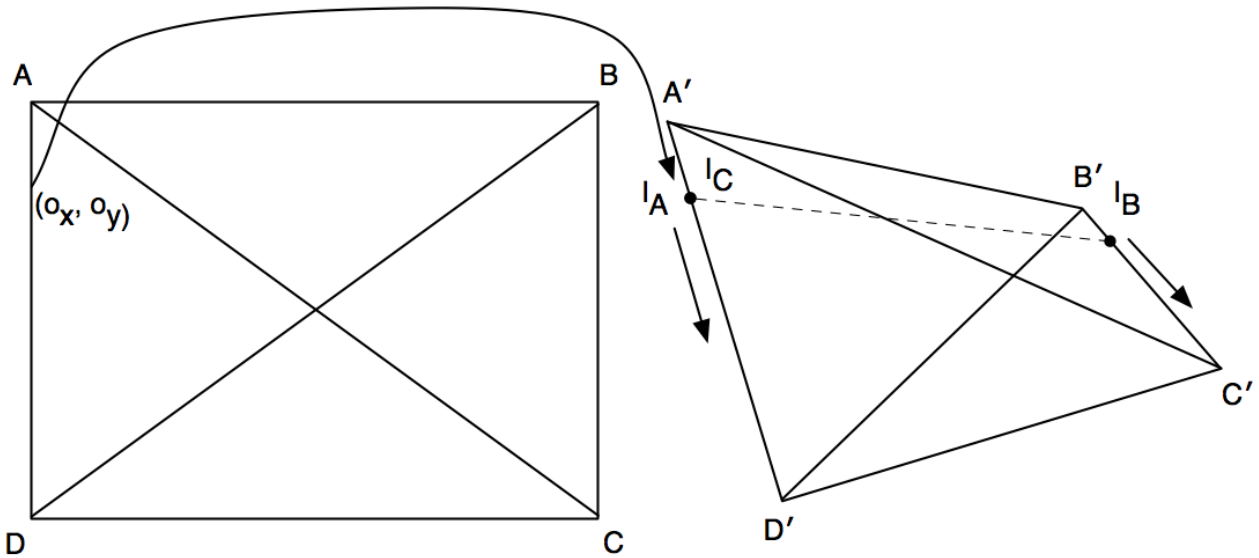

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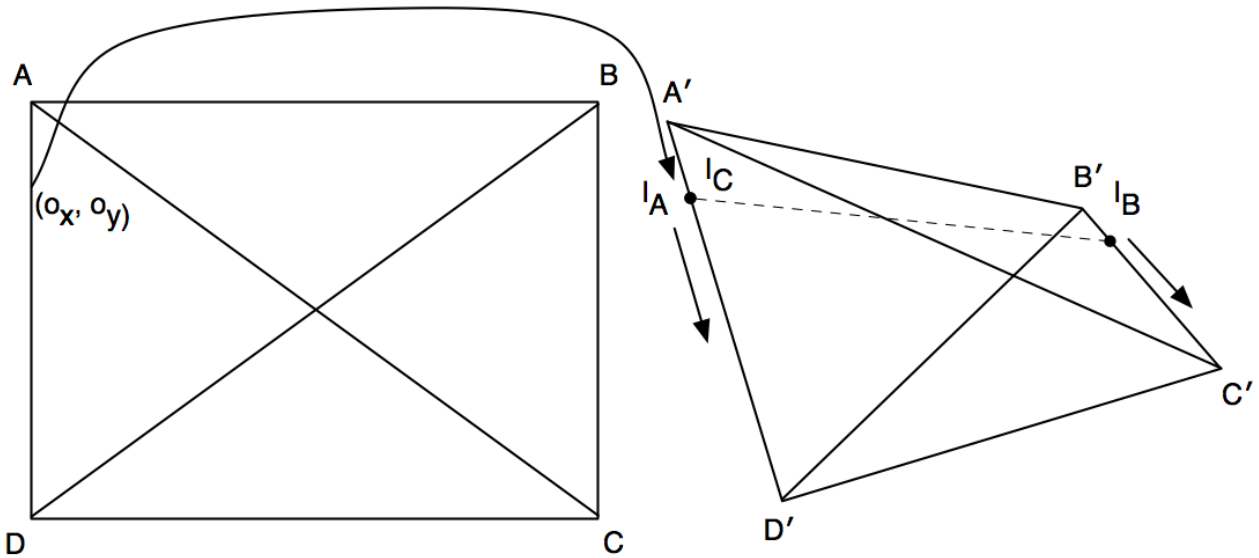

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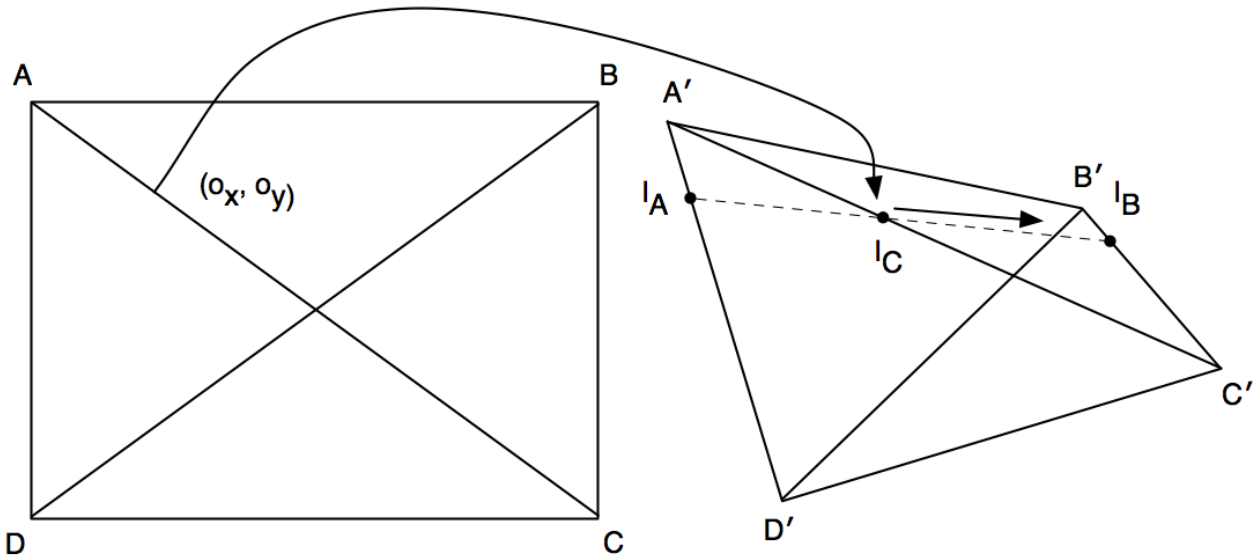

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`projective_transform`: Example

Figure: The original image

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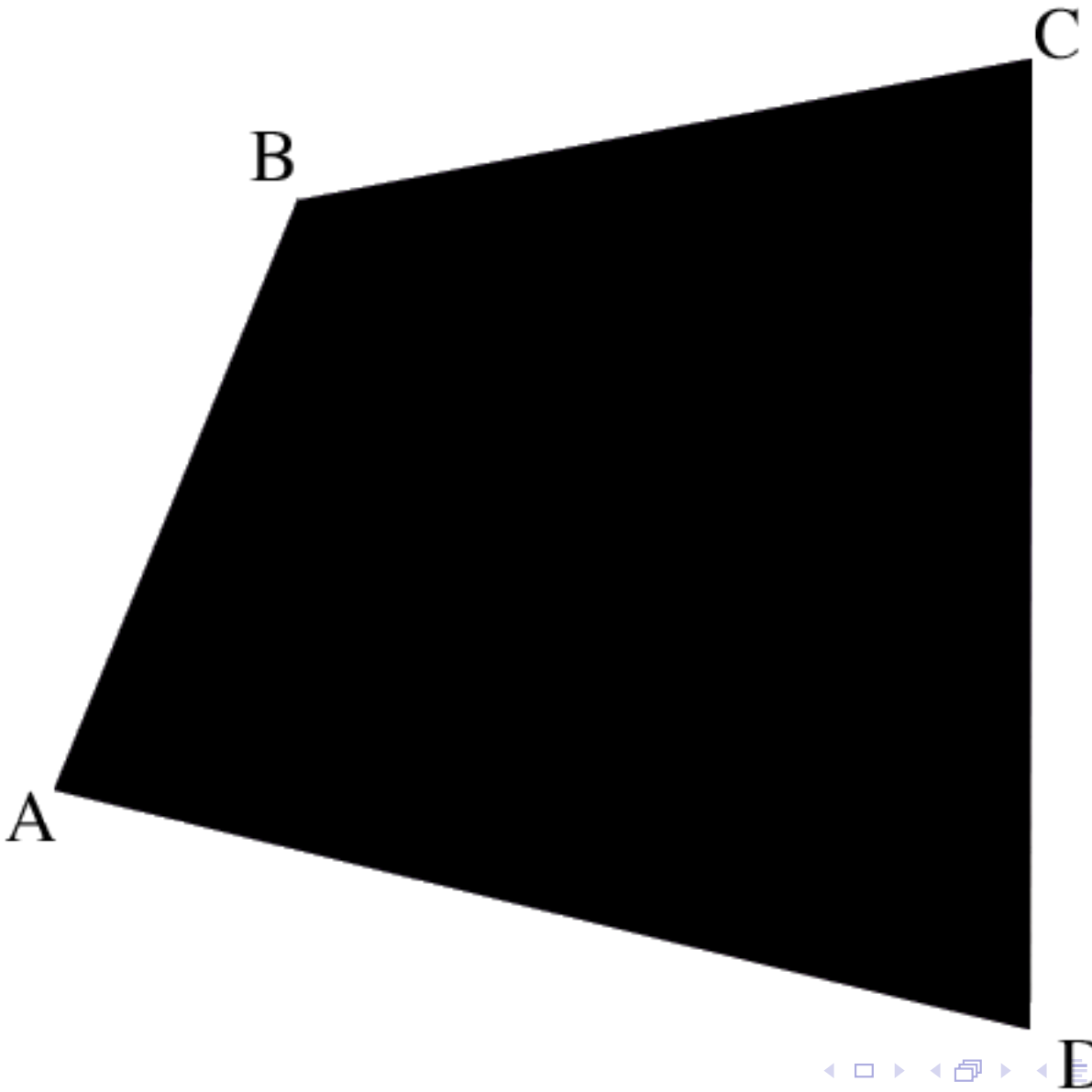

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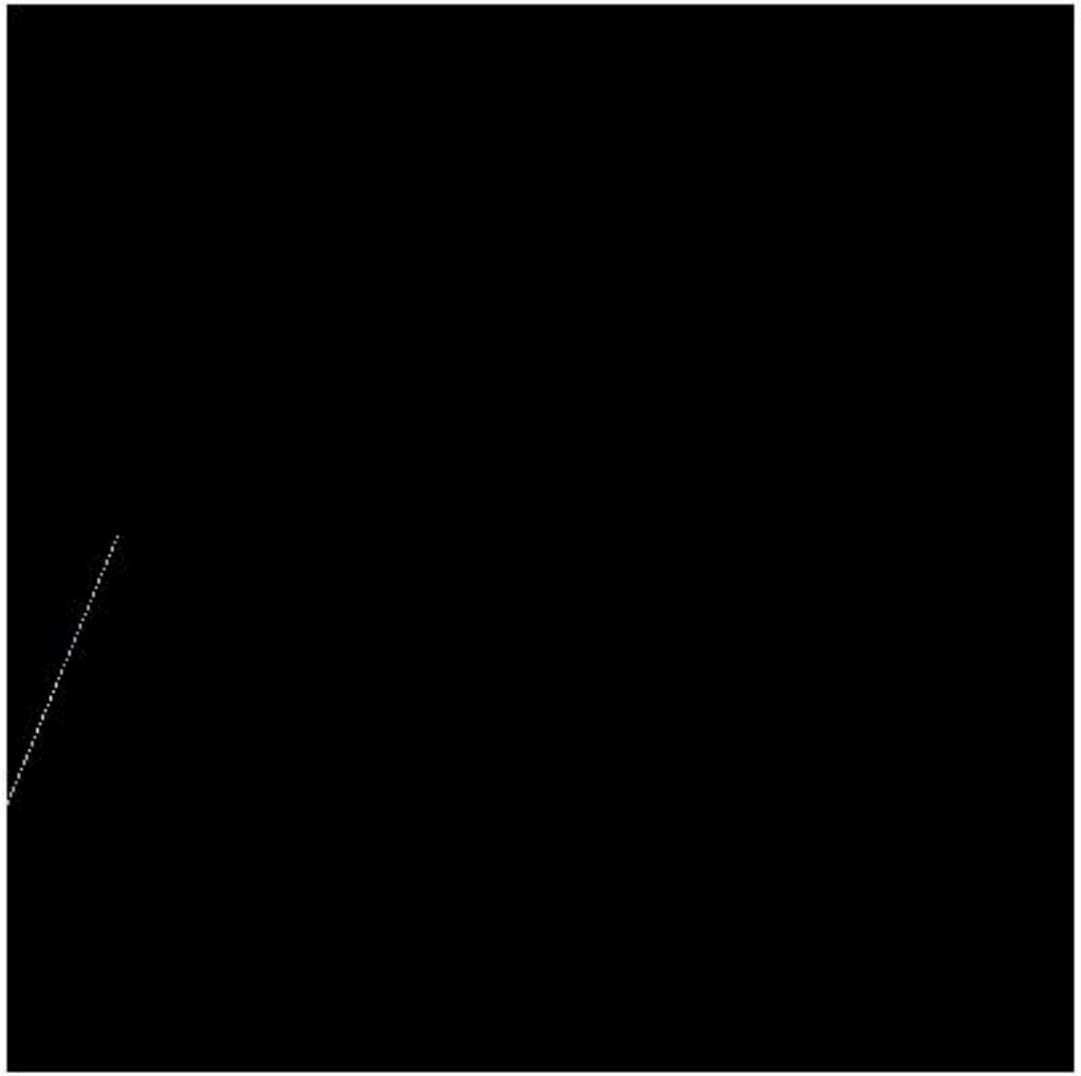

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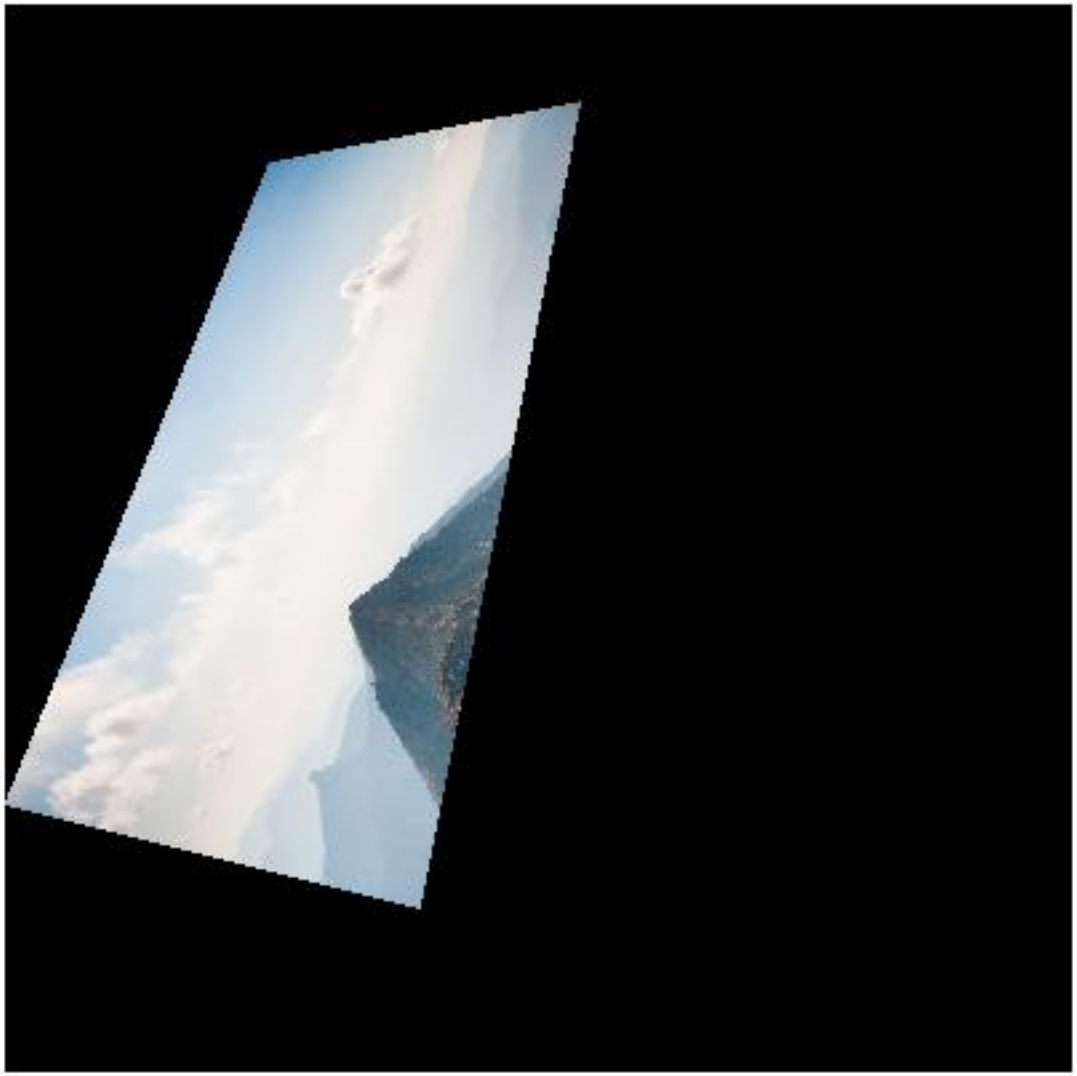

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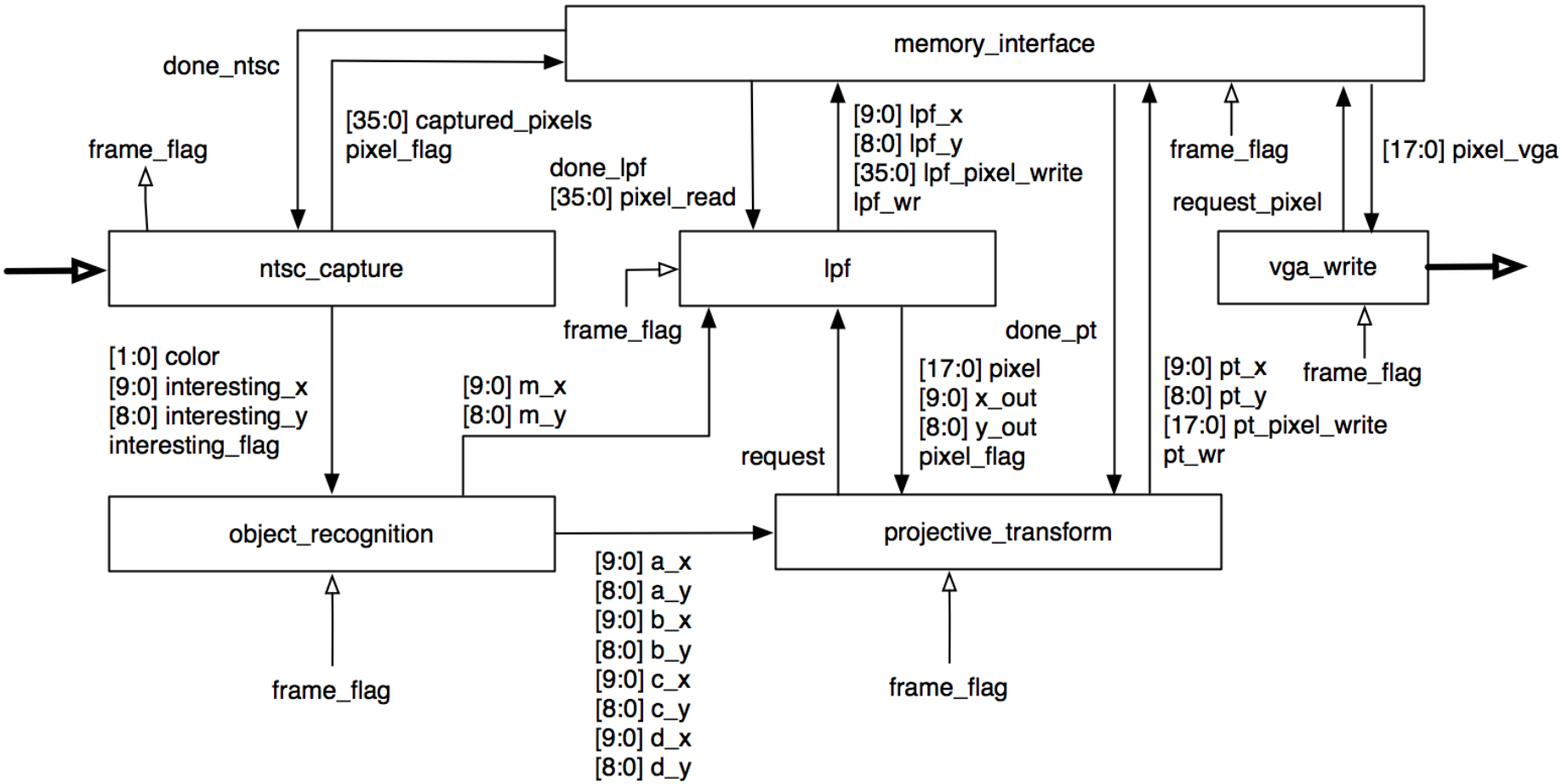
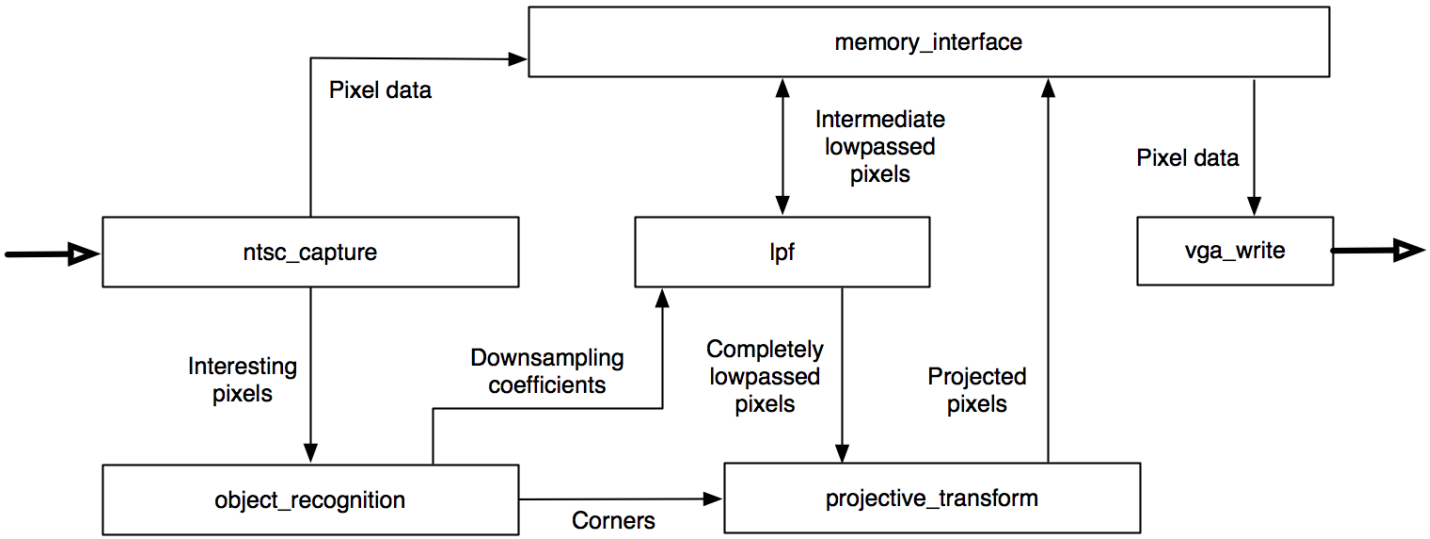
- Processes pixels "on-the-fly" from `LPF`
- Negligible BRAM memory requirements (a handful of registers)

projective_transform: How it Interfaces



object_recognition



- Mark corners of frame with four differently colored dots.
- Recognition begins in the `ntsc_capture` module, which detects these colors as it is capturing data and sends the pixel info to the `object_recognition` module.

object_recognition

- Take linear weighted center of mass for each color
- Sums the (x,y) coordinates for each color as it receives them. (8 running sums, 2 for each color)
- When the frame is done, divide each sum by the number of summed items
- The resulting 4 (x,y) pairs are the corners of the frame
- By looking for pixels in `ntsc_capture` we significantly reduce the amount of time spent in `object_recognition`

`LPF`: its purpose

- `projective_transform` → aliasing

Original

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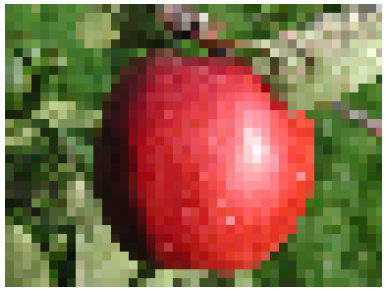

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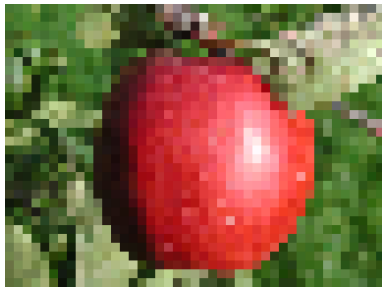

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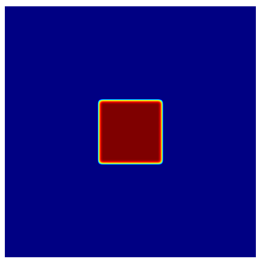

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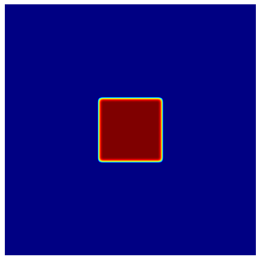

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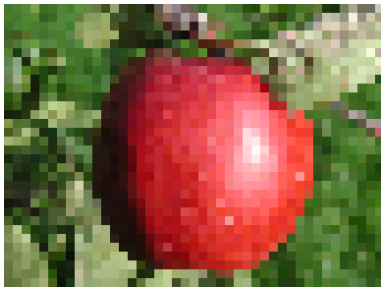

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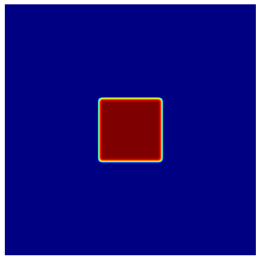

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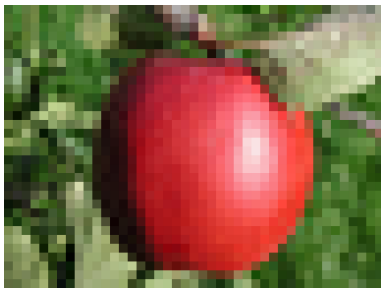

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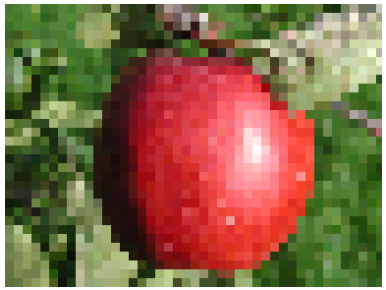

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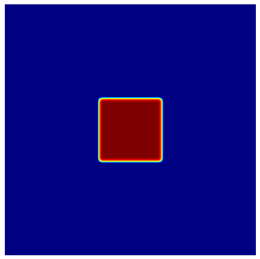

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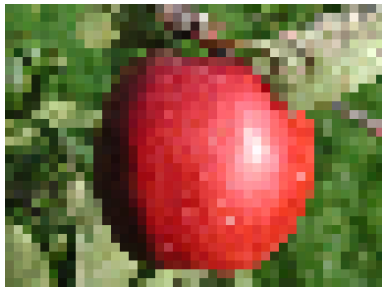

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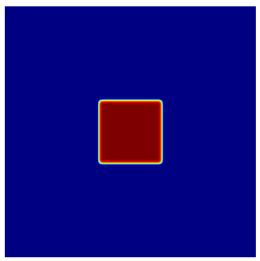

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- Parks-McClellan: reasonable accuracy, symmetric, easily calculable

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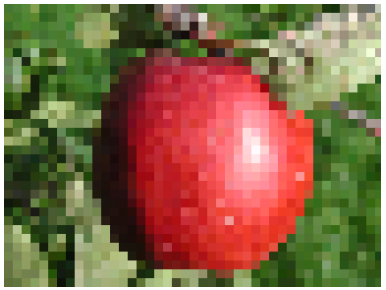

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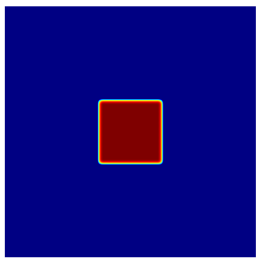

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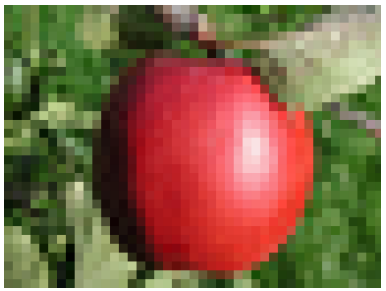

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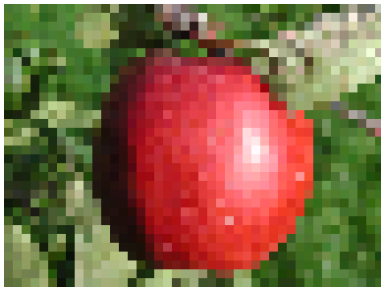
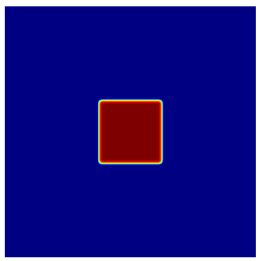
- FIR PM filter reduces mem. acceses to 1.5/pixel

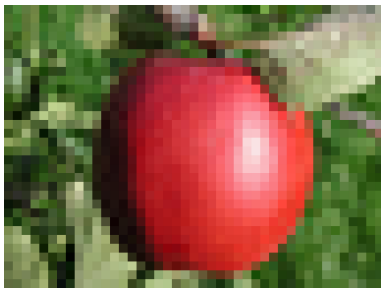
Original



Aliased



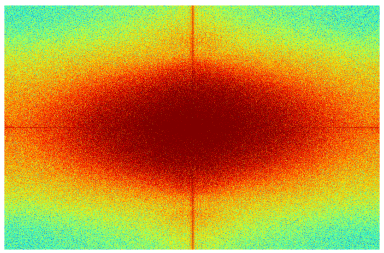
Mag. of Filter



Filtered

LPF: the algorithm

1. Given an arbitrary image & skewing coefficients M_x & M_y.

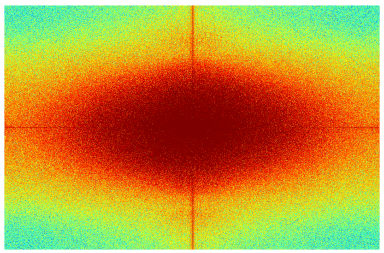


F.T. Original

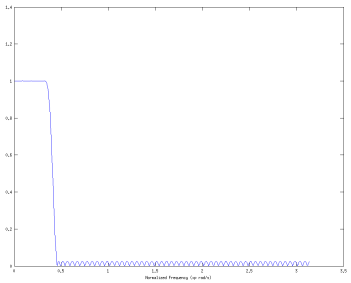
Original Image

LPF: the algorithm

1. Given an arbitrary image & skewing coefficients M_x & M_y.
2. Fetch a filter with cutoff $\frac{\pi}{M_y}$.



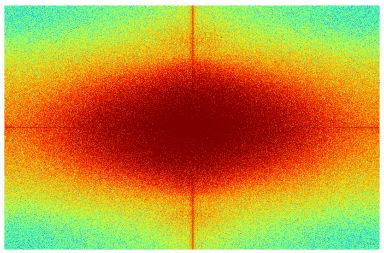
F.T. Original



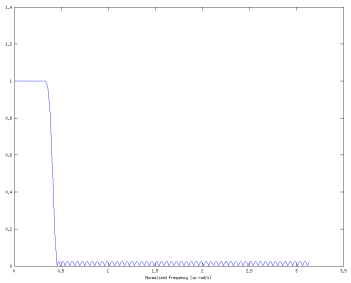
1D FIR, $\omega_c = \frac{\pi}{8}$

LPF: the algorithm

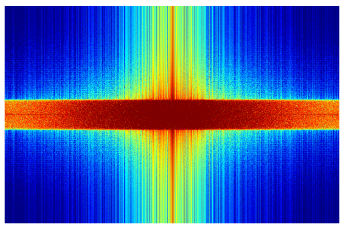
1. Given an arbitrary image & skewing coefficients M_x & M_y.
2. Fetch a filter with cutoff $\frac{\pi}{M_y}$.
3. Filter each column and store in memory.



F.T. Original



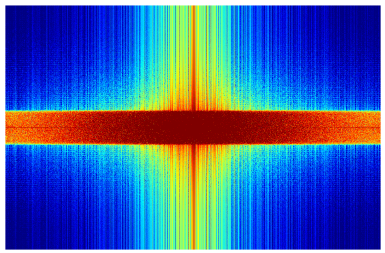
1D FIR, $\omega_c = \frac{\pi}{8}$



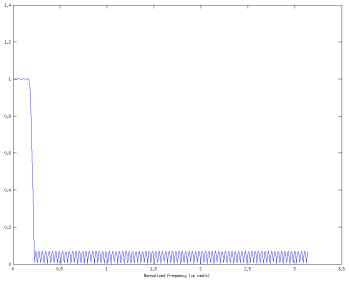
F.T. Filtered

LPF: the algorithm

1. Given an arbitrary image & skewing coefficients M_x & M_y.
2. Fetch a filter with cutoff $\frac{\pi}{M_y}$.
3. Filter each column and store in memory.
4. Fetch a filter with cutoff $\frac{\pi}{M_x}$.



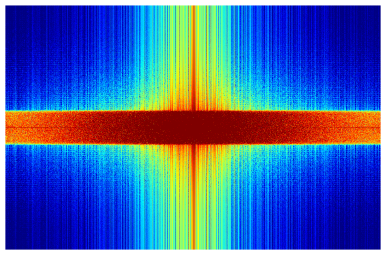
F.T. Filtered



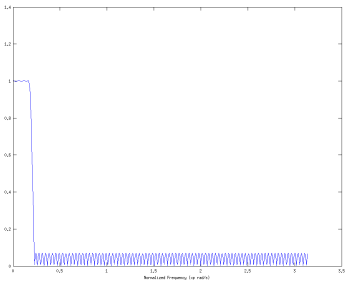
1D FIR, $\omega_c = \frac{\pi}{16}$

`LPF`: the algorithm

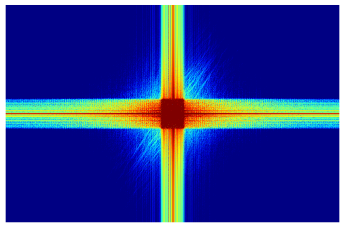
1. Given an arbitrary image & skewing coefficients M_x & M_y.
2. Fetch a filter with cutoff $\frac{\pi}{M_y}$.
3. Filter each column and store in memory.
4. Fetch a filter with cutoff $\frac{\pi}{M_x}$.
5. Filter each row and output to `projective_transform`.



F.T. Filtered



1D FIR, $\omega_c = \frac{\pi}{16}$

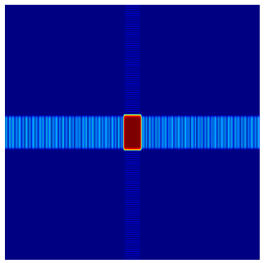


F.T. Output

`LPF`: the algorithm

1. Given an arbitrary image & skewing coefficients M_x & M_y.
2. Fetch a filter with cutoff $\frac{\pi}{M_y}$.
3. Filter each column and store in memory.
4. Fetch a filter with cutoff $\frac{\pi}{M_x}$.
5. Filter each row and output to `projective_transform`.
6. Repeat this process every refresh cycle.

Original



F.T. of Process

Output

memory_interface

- 1 image is a lot of data:
  $640 \cdot 480 \cdot 24$ bits ≈ 0.88MiB

memory_interface

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- Total BRAM: 0.316MiB

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  $640 \cdot 480 \cdot 24$ bits ≈ 0.88MiB
- Total BRAM: 0.316MiB
- We need to store 4 images in memory!

memory_interface

- 1 image is a lot of data:
  $640 \cdot 480 \cdot 24$ bits $\approx$ 0.88MiB
- Total BRAM: 0.316MiB
- We need to store 4 images in memory!
- Let's use the ZBT RAM: $2 \cdot$ 2.25MiB

memory_interface

- 1 image is a lot of data:
  $640 \cdot 480 \cdot 24$ bits ≈ 0.88MiB
- Total BRAM: 0.316MiB
- We need to store 4 images in memory!
- Let's use the ZBT RAM: $2 \cdot 2.25$MiB
- Not so fast: 1 clock cycle per memory access

memory_interface

- 1 image is a lot of data:
  $640 \cdot 480 \cdot 24$ bits ≈ 0.88MiB
- Total BRAM: 0.316MiB
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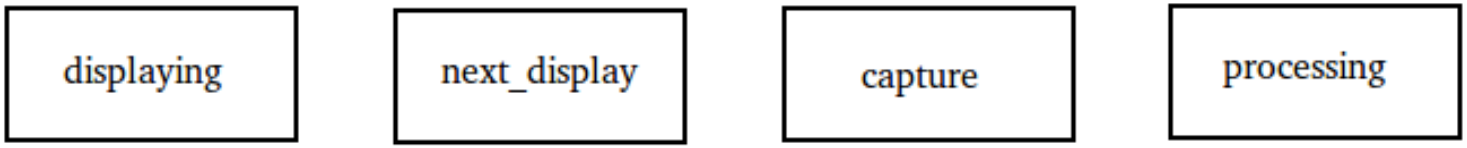
- 1 pixel per address would require a clock speed $> 100MHz$

memory_interface

- 1 image is a lot of data:
  $640 \cdot 480 \cdot 24$ bits ≈ 0.88MiB
- Total BRAM: 0.316MiB
- We need to store 4 images in memory!
- Let's use the ZBT RAM: $2 \cdot 2.25$MiB
- Not so fast: 1 clock cycle per memory access
- 1 pixel per address would require a clock speed $> 100MHz$
- Let's store store 18 bits per pixel or 2 per address

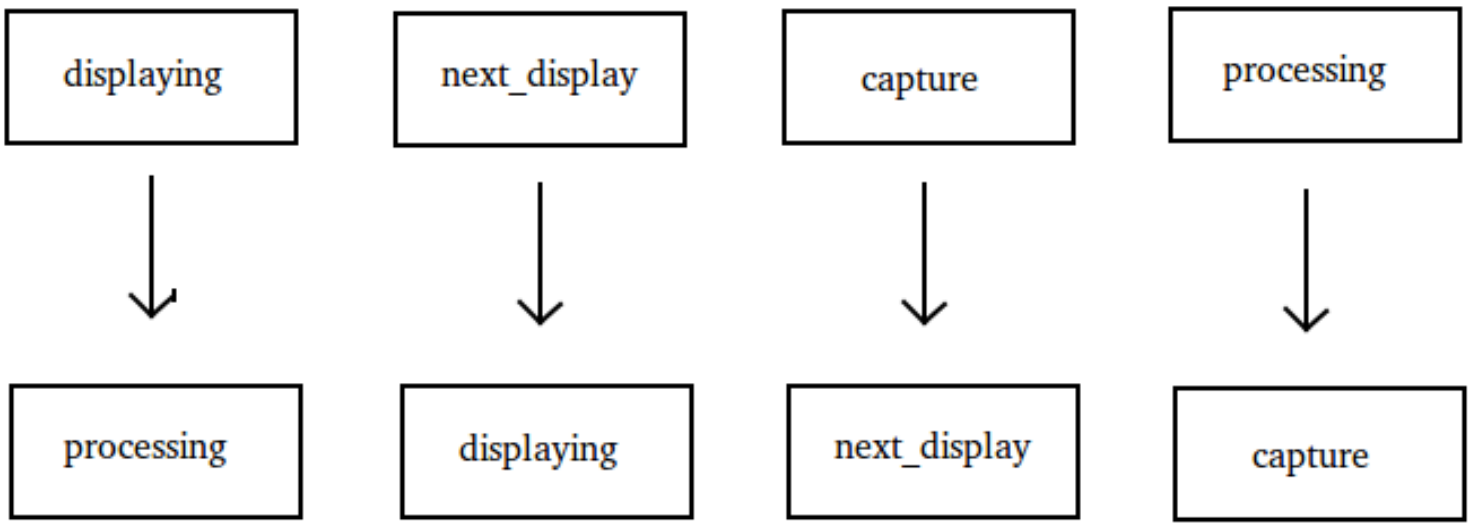
`memory_interface`: operation

Four images in memory:



memory_interface: operation

Four images in memory:



Shift every refresh cycle

system io: ntsc_capture & vga_write

ntsc_capture

system io: `ntsc_capture` & `vga_write`

`ntsc_capture`

- Image data streaming from camera

system io: `ntsc_capture` & `vga_write`

`ntsc_capture`

- Image data streaming from camera
- New image every $\frac{1}{30}$ seconds

system io: `ntsc_capture` & `vga_write`

`ntsc_capture`

- Image data streaming from camera
- New image every $\frac{1}{30}$ seconds
- Module will be adapted from NTSC code on 6.111 website

system io: `ntsc_capture` & `vga_write`

`ntsc_capture`

- Image data streaming from camera
- New image every $\frac{1}{30}$ seconds
- Module will be adapted from NTSC code on 6.111 website
- Requires own clock (ISE)

system io: `ntsc_capture` & `vga_write`

`ntsc_capture`

- Image data streaming from camera
- New image every $\frac{1}{30}$ seconds
- Module will be adapted from NTSC code on 6.111 website
- Requires own clock (ISE)
- Outputs two pixels to `memory_interface`

system io: `ntsc_capture` & `vga_write`

`ntsc_capture`

- Image data streaming from camera
- New image every $\frac{1}{30}$ seconds
- Module will be adapted from NTSC code on 6.111 website
- Requires own clock (ISE)
- Outputs two pixels to `memory_interface`

`vga_write`

system io: `ntsc_capture` & `vga_write`

`ntsc_capture`

- Image data streaming from camera
- New image every $\frac{1}{30}$ seconds
- Module will be adapted from NTSC code on 6.111 website
- Requires own clock (ISE)
- Outputs two pixels to `memory_interface`

`vga_write`

- Image data streamed to monitor

system io: `ntsc_capture` & `vga_write`

`ntsc_capture`

- Image data streaming from camera
- New image every $\frac{1}{30}$ seconds
- Module will be adapted from NTSC code on 6.111 website
- Requires own clock (ISE)
- Outputs two pixels to `memory_interface`

`vga_write`

- Image data streamed to monitor
- New image every $\frac{1}{60}$ seconds

system io: `ntsc_capture` & `vga_write`

`ntsc_capture`

- Image data streaming from camera
- New image every $\frac{1}{30}$ seconds
- Module will be adapted from NTSC code on 6.111 website
- Requires own clock (ISE)
- Outputs two pixels to `memory_interface`

`vga_write`

- Image data streamed to monitor
- New image every $\frac{1}{60}$ seconds
- Module will be adapted from Lab 3 VGA code

system io: `ntsc_capture` & `vga_write`

`ntsc_capture`

- Image data streaming from camera
- New image every $\frac{1}{30}$ seconds
- Module will be adapted from NTSC code on 6.111 website
- Requires own clock (ISE)
- Outputs two pixels to `memory_interface`

`vga_write`

- Image data streamed to monitor
- New image every $\frac{1}{60}$ seconds
- Module will be adapted from Lab 3 VGA code
- Requires own clock (ISE)

system io: `ntsc_capture` & `vga_write`

`ntsc_capture`

- Image data streaming from camera
- New image every $\frac{1}{30}$ seconds
- Module will be adapted from NTSC code on 6.111 website
- Requires own clock (ISE)
- Outputs two pixels to `memory_interface`

`vga_write`

- Image data streamed to monitor
- New image every $\frac{1}{60}$ seconds
- Module will be adapted from Lab 3 VGA code
- Requires own clock (ISE)
- `memory_interface` will feed properly formatted pixels

Timeline

11-11-2011	Finalized block diagram
11-18-2011	First drafts of `projective_transform` and `memory_interface` written
11-22-2011	First drafts of `object_recognition`, `LPF`, `vga_write`, and `ntsc_capture` first drafts written; `projective_transform` and `memory_interface` fully tested
11-28-2011	`ntsc_capture` and `vga_write` fully tested; start of basic integration
11-31-2011	`object_recognition` and `LPF` fully tested; start of full integration
12-05-2011	Full integration complete
12-12-2011	Final report due