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Assignment 2: Polarization-based Imaging

Reflectance separation in available datasets

Read and display polarization images

For each dataset (Remote and Apple), the nine high-dynamic-range TIFF images were read following the naming convention:

- **$s_0 \equiv L$**: intensity without polarization.
- **i_h^0, i_h^{90}, i_h^{45}, i_h^{135}**: under horizontally polarized illumination, with camera polarizer at 0°, 90°, 45°, and 135°.
- **i_v^0, i_v^{90}, i_v^{45}, i_v^{135}**: under vertically polarized illumination, same camera angles.

A single scale factor was applied to all images in `imagesc` to prevent over- or under-exposure.

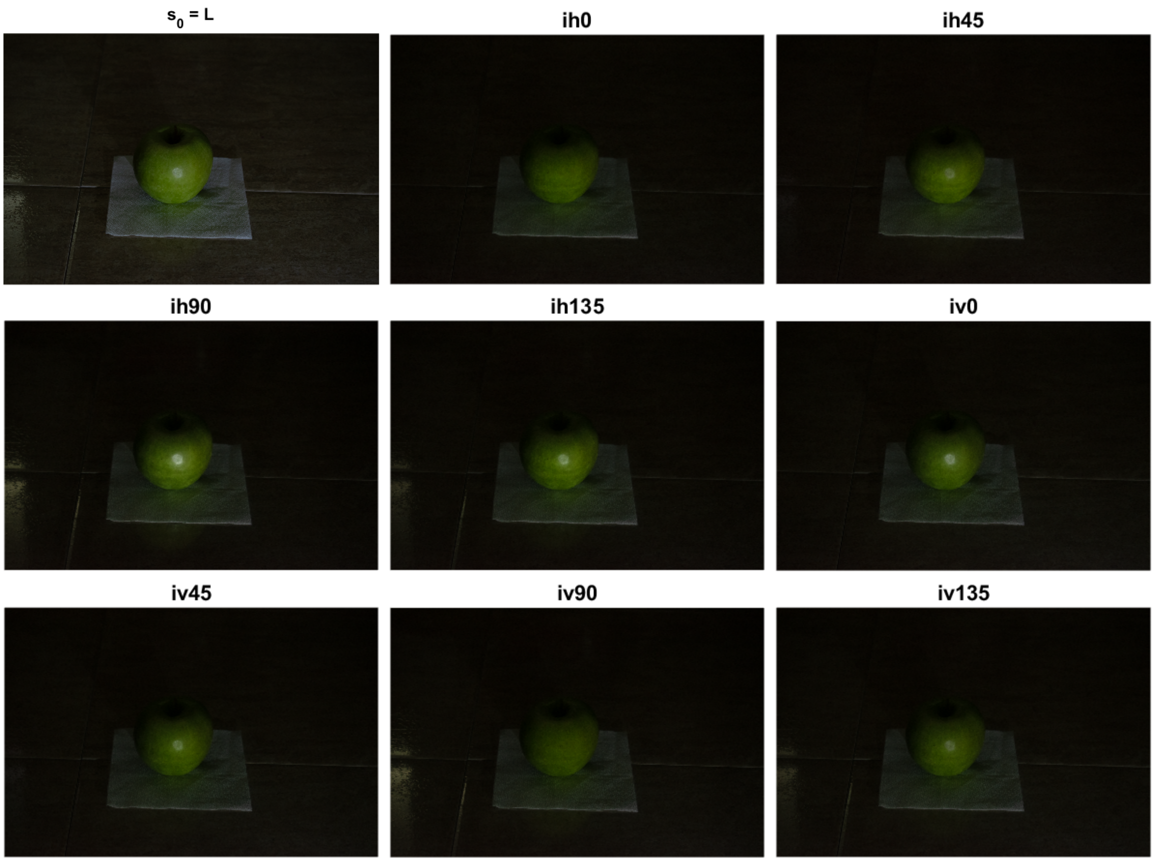

Figure 1: Example visualizations of $i_h\theta$ and $i_v\theta$ for the Apple dataset.

Second and third components of the Stokes vector

From each set $\{ih^0, ih^{90}, ih^{45}, ih^{135}\}$ and $\{iv^0, iv^{90}, iv^{45}, iv^{135}\}$, we computed:

$$s_{[h|v],1} = i^{0}_{[h|v]} - i^{90}_{[h|v]}$$
$$s_{[h|v],2} = i^{45}_{[h|v]} - i^{135}_{[h|v]}$$

These were displayed alongside s_0.

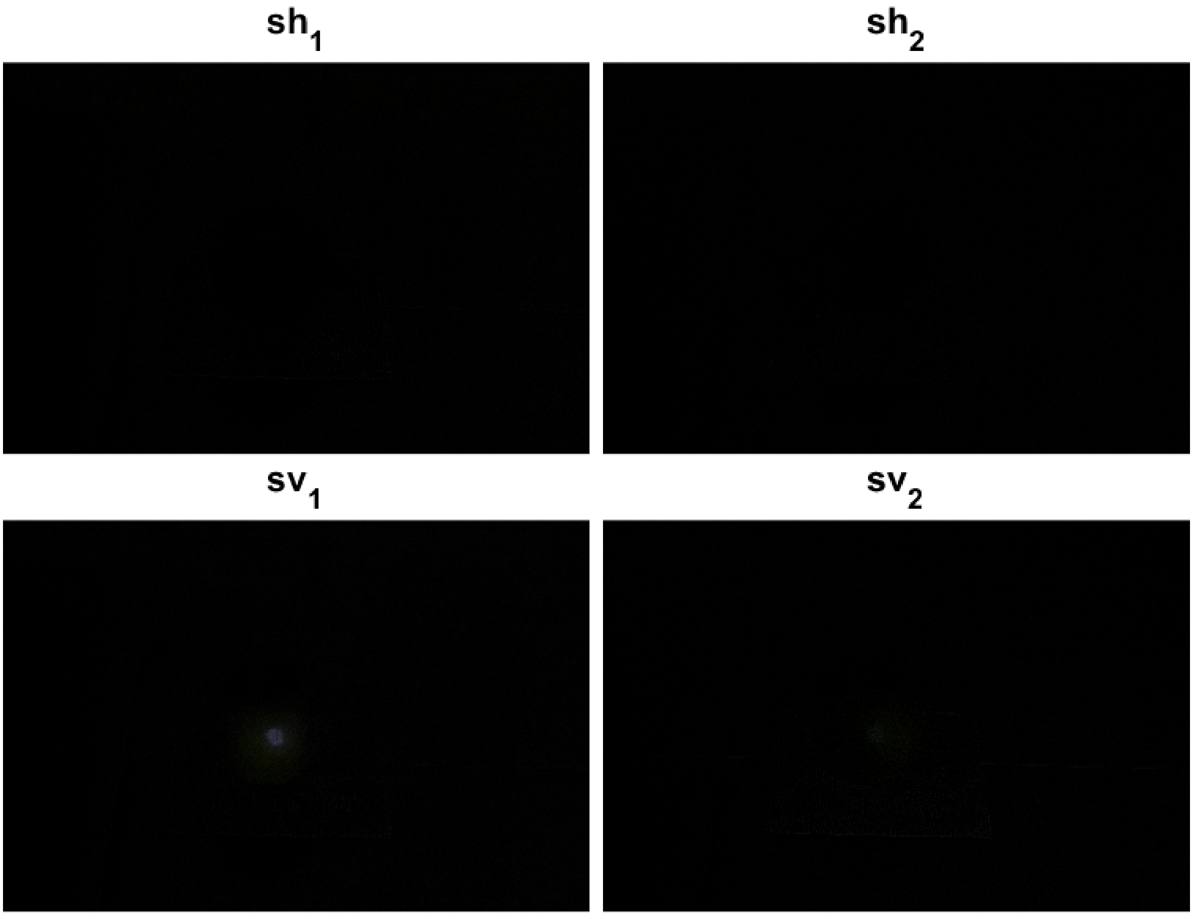

Figure 2: Stokes components $s_{h,1}$, $s_{h,2}$ (top row) and $s_{v,1}$, $s_{v,2}$ (bottom row) for the Apple dataset.

Reflectance separation

Using the Stokes components, we derived three reflectance images:

1. **Diffuse Polarized**

$$s_{dp,1} = s_{h,1} - s_{v,1} \qquad s_{dp,2} = s_{h,2} - s_{v,2} \qquad s_{dp,0} = s_{dp,1} - s_{dp,2}$$

2. **Specular Polarized**

$$s_{sp,1} = s_{v,1} - s_{dp,1} \qquad s_{sp,2} = s_{v,2} - s_{dp,2} \qquad s_{sp,0} = s_{sp,1} - s_{sp,2}$$

3. **Diffuse Unpolarized**

$$s_{du,0} = s_0 - s_{dp,0} - s_{sp,0}$$

Figure 3: Comparison of s_0, $s_{(dp),0}$, $s_{(sp),0}$, and $s_{(du),0}$ for the Apple dataset.

Comments:

- $s_{(dp),0}$ highlights matte and subsurface scattering regions.
- $s_{(sp),0}$ emphasizes shiny edges and specular highlights.
- $s_{(du),0}$ shows the total diffuse component free of polarized residuals.

Reflectance separation in your own datasets

Capture your own datasets

Nine images per object were captured following the same filter sequence:

- **Red metal canteen**: predominantly specular surface.
- **Green dragon figurine**: strong polarized specular reflection and some subsurface scattering.
- **Plastic Groot figurine**: moderate specular and subsurface.
- **Iridescent phone case**: principal color light blue, shifting to pink, red, or green with angle and lighting.

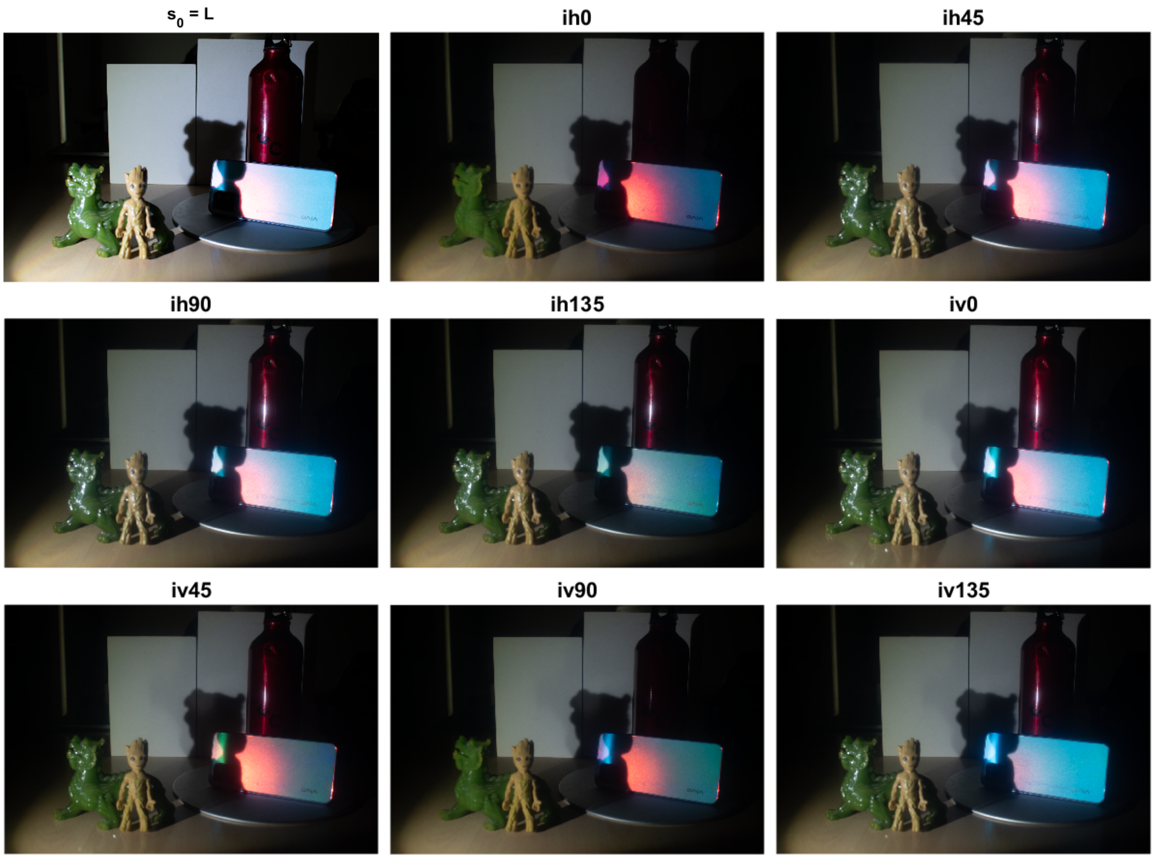

Figure 4: $i_h\theta$ and $i_v\theta$ images for the scene with the iridescent phone case.

Calculate Stokes images

The Stokes components s_1 and s_2 were computed for both illumination orientations:

- $s_{h,1}$, $s_{h,2}$; $s_{V,1}$, $s_{V,2}$.

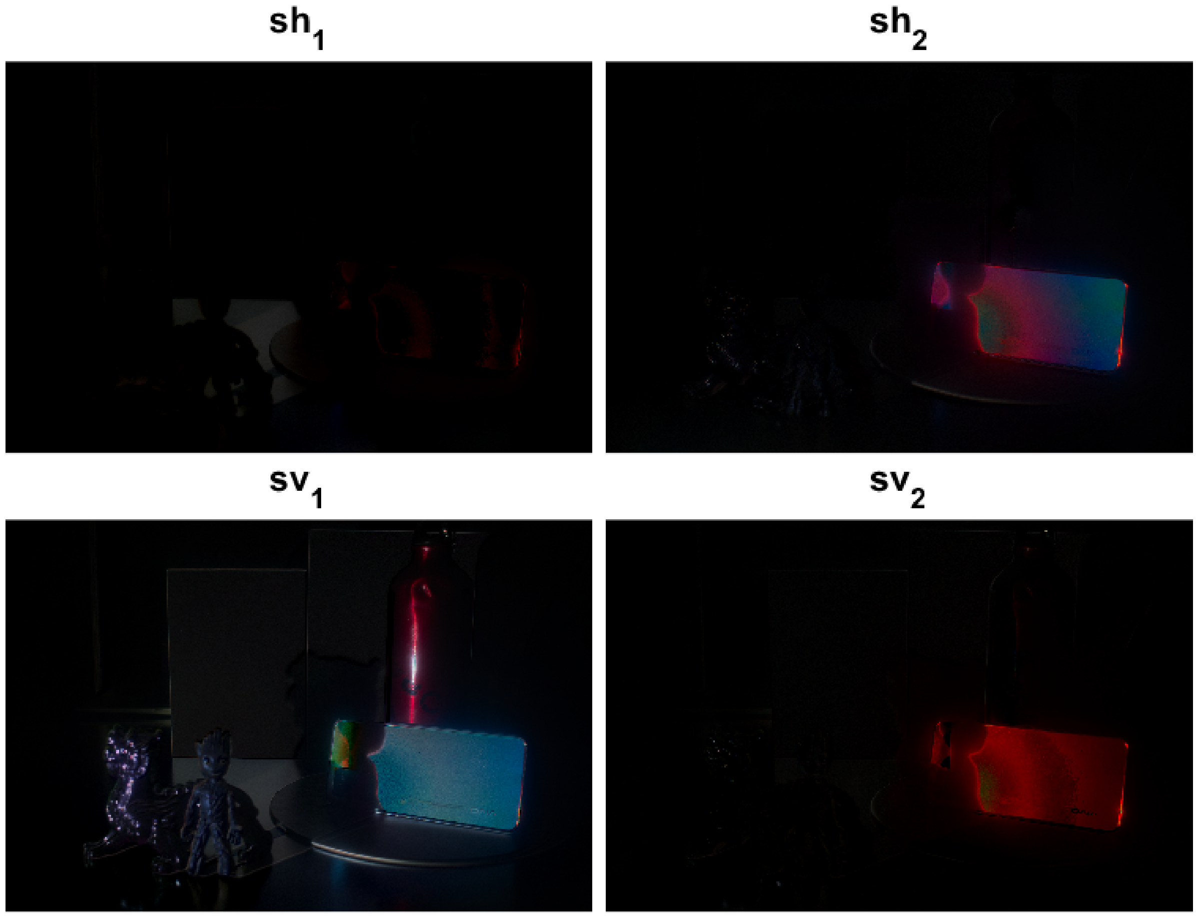

Figure 5: Stokes maps (s_0, s_1, s_2) for each captured object.

Calculate reflectance images

It was extracted:

- **Diffuse polarized** ($s_{(dp),0}$)
- **Specular polarized** ($s_{(sp),0}$)
- **Diffuse unpolarized** ($s_{(du),0}$)

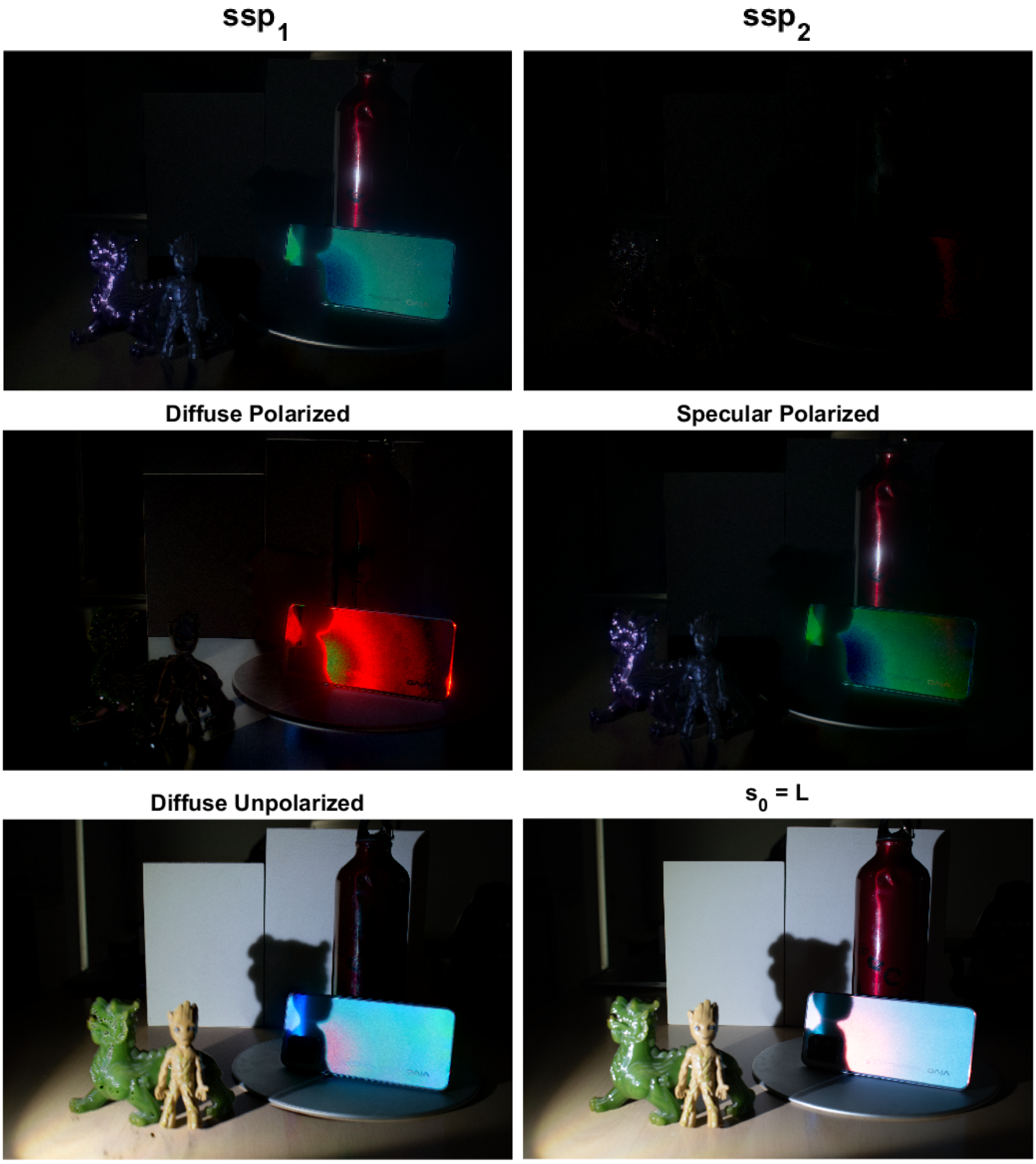

Figure 6: Comparison of the three reflectance components per object.

General Comments:

- The red canteen shows strong $s_{(sp)}$ at edges and negligible $s_{(dp)}$.
- The dragon and Groot exhibit mixtures of diffuse and specular depending on surface roughness.
- The iridescent case displays the most complex color patterns (see explanation below).

Explanation of Phone-Case Iridescence

The iridescent phone case exhibits **structural coloration** arising from a multilayer thin-film and micro-structured coating that splits white light into angle-dependent hues. Its behavior under polarized imaging is explained by three main optical phenomena:

1. **Thin-Film Interference:**
    - Light reflecting from the top and bottom interfaces of a dielectric film (thickness on the order of visible wavelengths) interferes constructively or destructively depending on path difference and angle of incidence.
    - Constructive interference at specific angles enhances certain wavelengths: in this case, green dominates at specular angles in the co-polarized channel, while red dominates in the cross-polarized diffuse channel.
    - Bright highlights may mix residual specular and diffuse wavelengths, yielding yellow in the diffuse-polarized image and dark blue in intensely illuminated specular regions.
2. **Fresnel Reflectance & Polarization:**
    - Fresnel's equations predict polarization-dependent reflectance: s-polarized light reflects more strongly than p-polarized at grazing angles (Brewster's angle phenomenon).
    - A co-polarized (parallel) capture emphasizes the mirror-like specular reflection (green peak), while a cross-polarized (orthogonal) capture suppresses it, isolating the depolarized diffuse scattering (red peak).
3. **Polymer Birefringence:**
    - The plastic layers in the case are birefringent due to internal stress or oriented polymer chains.
    - Birefringence introduces phase shifts between orthogonal polarization components, altering the apparent hue of scattered light under polarization.
    - This can attenuate shorter wavelengths in the diffuse channel and shift them under crossed polarizers, enhancing red appearance in $s_{(}\mathrm{dp}_{),0}$.