Blending Workshop Breakout Session #5

Tools and Data Sets for Developing and Evaluating Algorithms for Blended Objects

Wednesday, August 15, 1:30 to 3:00pm
Agenda

1. Combining existing space & ground imaging - overview - Harry Ferguson
   ○ Example: HST/HSC - Will Dawson
2. Catalog-based simulations - two blending-analysis examples here.
3. Pixel-level simulation tool kits -
   ○ Example 1: Weak Lensing Deblending package - David Kirkby
   ○ Example 2: Blending Tool Kit - Sowmya Kamath
   ○ Example 3: Chromatic Real Galaxy - Sowmya Kamath
4. Generative models for simulation - overview & examples - David Kirkby
5. Simulations embedded in real data -
   ○ Example: Balrog (Dark Energy Survey) - Eric Huff
6. Discussion and planning
Hubble Datasets useful for blending tests

**HST**
- ACS I-band=F814W, 0.09" FWHM, 0.05" pixels, 203" x 203"

**CANDELS** [candels.ucolick.org](http://candels.ucolick.org) 0.2 deg², 5 fields
  - Point-source limit ~27
  - H-band selected catalog
    - 0.17" FWHM PSF
    - De-blended ground-based and Spitzer photometry using HST positional priors
  - Deepest fields for multi-wavelength coverage
  - Dense & deep spectroscopic followup

**COSMOS** [http://cosmos.astro.caltech.edu/page/astronomers](http://cosmos.astro.caltech.edu/page/astronomers)
- 1.78 deg² centered at (RA,DEC) = (150.2, 2.2).
- 50% completeness for sources 0.5" in diameter at I(AB) = 26.0 mag.
- Position-matched ground-based and Spitzer photometry
CANDELS

- Catalogs coming soon:
  - Photo-z
    - Kodra+18
    - Updated phot-z from 5 codes
      - With PDFs
    - best available spec-z
  - GOODS-N photometry
    - Barro+18
    - Photo-z make use of 25-band R=50 data & HST grism data over much of the field
Using HST images as “truth”

+ They are real
+ Avoids having to use models or make individual-galaxy cutouts
+ Best available redshift estimates
  - Don’t really know truth
    - Even total magnitudes are uncertain
  - <200 sq. arcminute much deeper than LSST
+ CANDELS catalog is not based on the highest-resolution data
  - Could reprocess using Scarlet starting with ACS 0.9” FWHM images
Using HST-like simulations as “truth”

+ True redshifts are known even for 100% overlap
+ Starts with a noiseless image
+ Easier to simulate LSST bandpasses
- Still some subtleties in estimating true total magnitudes
- Morphologies & SEDs not perfect
- So far, tiny areas (10’s of sq. arcmin)

Snyder+ Illustris mock images

https://github.com/gsnyder206/mock-surveys
Stress test: HST Frontier Fields

6 clusters & parallel fields (~60 sq. arcmin total)

- Deepest cluster fields
- Extensive multi-wavelength data & spectroscopy
- Extensively tested lens models
- Very challenging de-blending problem even at HST resolution
- Immediate science from improving de-blending of these images
- Don’t really know truth
- Less multiwavelength data than CANDELS

<table>
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<th>Filter</th>
<th>Orbits</th>
<th>AB_mag</th>
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<tbody>
<tr>
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<td>18</td>
<td>28.8</td>
</tr>
<tr>
<td>F606W</td>
<td>10</td>
<td>28.8</td>
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<tr>
<td>F814W</td>
<td>42</td>
<td>29.1</td>
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<tr>
<td>F105W</td>
<td>24</td>
<td>28.9</td>
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<td>F125W</td>
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<tr>
<td>F140W</td>
<td>10</td>
<td>28.6</td>
</tr>
<tr>
<td>F160W</td>
<td>24</td>
<td>28.7</td>
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Space + ground data: HST + Suprime-Cam (SC)

Example: The Ellipticity Distribution of Ambiguously Blended Objects

● Goal:
  ○ Layout the fundamentals of ambiguous blending
  ○ Quantify the scale of the ambiguous blending problem
  ○ Estimate its impact on cosmic shear measures

● Method:
  ○ Use overlapping Subaru Suprime-Cam imaging (to LSST depth) and Hubble Space Telescope imaging
  ○

\[ \theta_{\text{eff},ij} = \frac{\theta_{ij}}{\Xi_\sigma (\sigma_i + \sigma_j)} \]

\( \sigma_j \): HST size after convolution with Subaru PSF
\( \Xi_\sigma \): Normalizing scale factor (1 reasonable choice)
\( \theta_{\text{eff},ij} < 1 \): Flagged as ambiguous blend candidate
Subaru (left) and HST (right) views of ambiguous blends

Dawson, Schneider, Tyson & Jee (2016)
Subaru (left) and HST (right) views of ambiguous blends

Dawson, Schneider, Tyson & Jee (2016)
The number density of ambiguous blends grows rapidly with depth, and they have significantly different properties

\[ n_B \approx 2.3n^{3.15} \times 10^{-6} \]

~14% of LSST Galaxies
Ambiguous Blends

Dawson, Schneider, Tyson & Jee (2016)
Catalog-level simulations: Two examples

These independent studies each estimate a specific blending impact on joint galaxy-galaxy, galaxy-shear and shear-shear correlations (3x2-pt correlations).

   ○ Uses Scinet Light Cone Simulations (SLICS) catalog.
   ○ Assumes either the faintest or both members of pairs of objects separated by less than a specified angle are excluded from the sample.
   ○ From the abstract: “For surveys like KiDS and DES, where the rejection of the neighbouring galaxies occurs within ~2 arcseconds, we show that the measured cosmic shear signal will be biased low, but by less than a percent on the angular scales that are typically used in cosmic shear analyses. The amplitude of the neighbour-exclusion bias doubles in deeper, LSST-like data.”

2. See presentation by Erfan Nourbakhsh at Blending Session #4 on study of impact of unrecognized blends.
   ○ Uses Buzzard catalog.
   ○ Assumes a fraction of pairs of objects separated by less than a specified angle are interpreted as a single object, impacting the measured position and shape.
Pixel-level simulation example 1: WeakLensingDeblending

Developed within the DESC to study blending impacts.

Galaxies, AGNs, stars…

Object properties, blending metrics, ...

readthedocs
tutorial
github
Default galaxy catalog from LSST CatSim:
- complete to $r \sim 28$
- easy to interface to other catalogs ([docs](#))
- galaxies described by 10 params:
  - Disk ($n=1$): $\text{flux}(\lambda)$, $q$, $h_lr$
  - Bulge ($n=4$): $\text{flux}(\lambda)$, $q$, $h_lr$
  - AGN: $\text{flux}(\lambda)$
Pixel-level simulation example 1: WeakLensingDeblending

Use simple instrument model to capture main scaling relations between surveys:
- camera: pixel size, zero point, exposure time.
- site: seeing, sky level, extinction.

<table>
<thead>
<tr>
<th>Survey</th>
<th>Effective Area $A$ (m$^2$)</th>
<th>Primary Diameter $D$ (m)</th>
<th>Pixel Size $\Delta_{\text{pix}}$</th>
<th>Exp. Time $t$ (s)</th>
<th>Sky Brightness $\mu$mag/arcsec$^2$</th>
<th>Atmos. FWHM $\kappa_0$</th>
<th>Zero Point $s_0$</th>
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<td>8.360</td>
<td>0.200&quot;</td>
<td>$i$ 5520</td>
<td>20.5</td>
<td>0.75&quot;</td>
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<td>$r$ 5520</td>
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<td>$i$ 1000</td>
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<td>$r$ 800</td>
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<td>0.79&quot;</td>
<td>15.7</td>
</tr>
</tbody>
</table>

=184 visits × 30s
Pixel-level simulation example 1: WeakLensingDeblending

Overall philosophy: quantify impacts of blending without using specific pipeline algorithms -
- identify overlapping source groups
- estimate params (SNR, size, ...) w/ and w/o blending
- estimate correlated statistical errors and noise bias on size & shape using pixel-level Fisher matrix formalism

Partial derivatives

```
flux  x  y  size  e1  e2
```

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Pixel-level simulation example 1: WeakLensingDeblending

**Blending metric example:**
"purity" = ratio of weighted pixel sums

\[ \rho_k = \frac{\sum_{\text{pix}} G_k G_k}{\sum_{\text{pix}} G_k (G_1 + G_2 + \ldots)} \]

![Blending example images](image.png)

- \( G_1 \) with \( r=26.0 \)
- \( G_2 \) with \( r=25.2 \)
- \( G_1 + G_2 \)

- \( \rho_1 = 0.58 \)
- \( \rho_1 = 0.78 \)
Results example: where is the statistical power for weak-lensing shape measurements?

"Detectable" => $\text{SNR}_{\text{grp, float}} > 6$
Pixel-level simulation example 1: WeakLensingDeblending

**Results example:** what is the impact of star-galaxy blending?

\[ \rho_* < 10 / \text{sq.arcmin}: \]
- \( A = 14.2 \text{K sq.deg} \)
- \( A_{\text{eff}} = 10.2 \text{K sq.deg} \)
Pixel-level simulation example 2: Blending Tool Kit

https://github.com/LSSTDESC/BlendingToolKit

- July 2018 DESC Hack Day project [Doux, Kamath, Lanusse, ...]
- Add-on for WeakLensingDeblending package for simulating images of multi-object blends (without analysis step).

- **Goal:** fast “on the fly” generation of images with different PSFs and different noise levels/realizations (for example, for data augmentation for ML training sets).
- Basic version available (with a [tutorial](https://github.com/LSSTDESC/BlendingToolKit)).
- Currently under development.
- Suggestions / requests are welcome!
Galsim RealGalaxy and ChromaticRealGalaxy classes can be used to decorrelate noise in HST images, and simulate LSST noise and PSF.

Datasets: real galaxy HST images with $I < 25.2$
- COSMOS (I band): $\sim 87,000$ galaxies
- AEGIS (V & I bands): $\sim 26,000$ galaxies

ChromaticRealGalaxy was used with AEGIS dataset to study impact of galaxy color gradients and wavelength dependent PSFs on shear measurements.
Generative models for simulation

Leverage recent advances in deep neural networks.

input

CLASSIFIER

elliptical or spiral?

AUTOENCODER
Generative models for simulation

Build sophisticated probabilistic models by decoupling encoder from decoder: 

Variational AutoEncoder
Kingma, Welling 2013

Generative-Adversarial Network
Goodfellow++ 2014
Generative models for simulation

Image processing state of the art:

Potential applications for blending simulation:

- Dense random sampling of a prior that is sparsely sampled from space / DDF.
- Sophisticated data augmentation technique for training deep neural networks.
Simulated objects embedded in data

- **Balrog**: GalSim objects in Dark Energy Survey data [Suchyta, Huff et al.]
- **SynPipe**: GalSim objects in Hyper Suprime-Cam data [Huong, Leauthaud, Murata et al.]
- LSST science pipeline (in progress).

** See [http://adsabs.harvard.edu/abs/2016MNRAS.457..786S](http://adsabs.harvard.edu/abs/2016MNRAS.457..786S)
Balrog: An injection pipeline for the Dark Energy Survey

Eric Huff (JPL) for
Sahar Allam, Gary Bernstein, Vinicius Busti, Ami Choi, Katie Eckert,
Spencer Everett, Nikolay Kuropatkin, Eli Rykoff, Erin Sheldon, Megan
Splettstoesser, Douglas Tucker, Reese Wilkinson, Brian Yanny, Yuanyuan
Zhang, and many others!
$P(\text{catalog} \mid \text{universe})$
Implementation
GalSim + Input catalogs

DECam, SISPI, DTS

Science Raw Preprocessing FIRSTCUT Reduced
Zeros, Dome Flats Super Calibrations
Nightly Calibrations

FIRSTCUT Reduced

Diff Image AUTSCAN

 Supernova Processing

SN eval (pass/fail)

FirstCut eval (pass/fail)

Coadd Image

MEDS, MOF, MetaCal

Photometric Redshifts

Mangle

Coadd Catalogs

Weak Lensing
Galaxy Clusters
Large Scale Structure/BAO

Analysis with SNIa Distances

Balrog catalogs

Identification

Single Epoch Processing
Balrog: The injection simulation package in the Dark Energy Survey
Balrog: The injection simulation package in the Dark Energy Survey
Implementation

Design Choices

1. COSMOS vs. deep fields
2. Injection rate & pattern vs. runtime
3. Full coverage vs. accurate population
4. Postage stamps vs. parametric
5. Signal injection vs. randoms
Fully realizing the survey is expensive

**Base+SWARP+SExtractor:** ~1h per tile  **Object Injection:** ~1h per tile

**SOF:** ~1.5h per tile

**MOF:** ~5h per tile

**Metacal:** ~2h per tile  **BFD:** ~1h per tile

**Total:** ~12 hours per tile per 16 core machine

100 dedicated Fermi DES machines with 16 CPU gives ~**50 days for entire Y3 footprint** for a single realization
Example: Hex grid injection saves factor of x2 in total compute time
Application to galaxy clustering
Links to other simulations, tools & examples

1. Simulations
   a. catalog level: DESC Data Challenge 2, Buzzard, Scinet Light Cone Simulations (SLICS), …
   b. pixel level
      ■ Weak Lensing Deblending package [David Kirkby]; based on GalSim
      ■ GPU-ready implementation of GalSim for data augmentation for ML [François Lanusse]
      ■ Blending Tool Kit: July 2018 DESC Hack Day project [C. Doux, S. Kamath, F. Lanusse, …]
      ■ AstrOmatic SkyMaker [Emmanuel Bertin, Pascal Fouquê]

2. Simulated objects embedded in real data
   a. Balrog: GalSim objects in Dark Energy Survey data [Eric Huff]
   b. SynPipe: GalSim objects in Hyper Suprime-Cam data [Huong, Leauthaud, Murata et al.]
   c. LSST science pipeline (in progress).

3. On-the-fly simulations for data augmentation
   a. On-the-fly GalSim image generation and caching with TensorFlow tf.data API: github repo [François Lanusse]