Conquering the Astronomical Data Flood through Machine Learning and Citizen Science

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The Problem: Big Data is a Big Challenge
LSST big data challenge #1

- **Each night** for 10 years LSST will obtain **roughly** the equivalent amount of data that was obtained by the entire Sloan Digital Sky Survey
- Our grad students will be asked to mine these data (~20 TB each night ≈ 40,000 CDs filled with data):
  - *A truckload of CDs each and every day for 10 yrs*
  - *Cumulatively, a football stadium full of 100 million CDs after 10 yrs*
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- The challenge is to find the new, the novel, the interesting, and **the surprises** (**the unknown unknowns**) within all of these data.
- **Yes, more is most definitely different!**
LSST big data challenge # 2

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Characterize first !
(Unsupervised Learning)

Classify later.
Characterization includes ...

- **Feature Detection and Extraction:**
  - Identifying and describing features in the data
    - via machine algorithms or human inspection *(including the potentially huge contributions from Citizen Science)*
  - Extracting feature descriptors from the data
  - Curating these features for search, re-use, & discovery
  - Finding other parameters and features from other archives, other databases, other information sources – and using those to help characterize (ultimately classify) each new event.
Data-driven Discovery (Unsupervised Learning) i.e., What can I do with characterizations?

1. Class Discovery – Clustering
2. Principal Component Analysis – Dimension Reduction
3. Outlier (Anomaly / Deviation / Novelty) Detection – Surprise Discovery
4. Link Analysis – Association Analysis – Network Analysis
5. and more.
The Promise: Big Data leads to Big Insights and New Discoveries

http://kdd2012.sigkdd.org/
Scary News:

Big Data is taking us to a Tipping Point

Good News: Big Data is Sexy

http://dilbert.com/strips/comic/2012-09-05/
There are many technologies associated with Big Data

http://siliconangle.com/blog/2012/07/13/big-data-nightmares/
One approach to Big Data: Hadoop and Map/Reduce (Computational Science)

Another approach to Big Data:
Data Science (Informatics)
A third approach to Big Data: Citizen Science (crowdsourcing)
Modes of Computing

• **Numerical Computation** (*in silico*)
  – Fast, efficient
  – Processing power is rapidly increasing
  – Model-dependent, subjective, only as good as your best hypothesis

• **Computational Intelligence**
  – Data-driven, objective (machine learning)
  – Often relies on human-generated training data
  – Often generated by a single investigator
  – Primitive algorithms
  – Not as good as humans on most tasks

• **Human Computation** (*Carbon-based Computing*)
  – Data-driven, objective (human cognition)
  – Creates training sets, Cross-checks machine results
  – Excellent at finding patterns, image classification
  – Capable of classifying anomalies that machines don’t understand
  – Slow at numerical processing, low bandwidth, easily distracted
Galaxy Zoo: example of Citizen Science (crowdsourcing)

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http://www.zooniverse.org

There are 2 main types of galaxies in the Universe: **Spiral** & **Elliptical** (plus there are some peculiar & irregular galaxies)
Gallery of Elliptical Galaxies

M32

M59

M87

M105

M110 = NGC205

M87 © Anglo-Australian Observatory
Photo by David Malin
Gallery of Face-on Spiral Galaxies
There are lots of Peculiar Galaxies also!
There are lots of things you can do with these peculiar galaxies ... 

- Spell your name in galaxies @
- http://writing.galaxyzoo.org
Galaxies Gone Wild!

Interacting Galaxies

Hubble Space Telescope • ACS/WFC • WFPC2

Colliding and Merging Galaxies = Interacting Galaxies

NASA, ESA, the Hubble Heritage (AURA/STScI)-ESA/Hubble Collaboration, and A. Evans (University of Virginia, Charlottesville/NRAO/Stony Brook University)
Merging/Colliding Galaxies are the building blocks of the Universe: $1+1=1$
Galaxy Mergers Zoo Gallery

Sloan image

Actual sky image.

Volunteer-selected models, based on viewing tens of thousands of real-time numerical simulations.

SDSS 587722984435351614

GALAXY ZOO
UNDERSTANDING COSMIC MERGERS
Galaxy Mergers Zoo Gallery

Sloan image

SDSS 587722984435351614
Galaxy Mergers Zoo Gallery

SDSS 587726033843585146
Galaxy Mergers Zoo Gallery

SDSS 587739646743412797
Galaxy Mergers Zoo Gallery

Sloan image

SDSS 587739721900163101

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Sloan image

SDSS 587727222471131318
Key Feature of Zooniverse: Data mining from the volunteer-contributed labels

• Train the automated pipeline classifiers with:
  – Improved classification algorithms
  – Better identification of anomalies
  – Fewer classification errors

• Millions of training examples (V&V)

• Hundreds of millions of class labels

• Statistics deluxe! …
  – Users (see paper: http://arxiv.org/abs/0909.2925 )
  – Uncertainty Quantification (UQ)
  – Classification certainty vs. Classification dispersion
Astroinformatics for Eventful Astronomy

- Report discoveries back to the science database for community reuse
- Basic astronomical objects (informatics granules) are annotated ...
  - with follow-up observations of any kind
  - with new knowledge discovered
  - with common knowledge
  - with inter-relationships between objects and their properties
  - with concepts
  - with context
  - With assertions (e.g., classifications, concepts, quality flags, relationships, references, observational parameters, common knowledge, inter-connectivity with other objects)
  - with experimental parameters
  - with observer / observatory descriptors
- Enables knowledge-sharing and reuse
Astroinformatics for Eventful Astronomy

- In order to facilitate filtering and prioritization of events for rapid follow-up observations, a near real-time **characterization** provider of tags (end-user annotations) for each object and event is needed.

- The semantic integration of real-time survey data products with federated VO-accessible archival information resources will facilitate the sharing of knowledge-rich quantifiable astronomical features (event characterizations) to the research community.

- An astroinformatics-enabled characterization service for large sky surveys provides uniform tags, metadata, labels, terminology.

- Use cases of the characterization service include knowledge capture, annotation, data mining, & queries of distributed knowledgebases.

- The addition of human-provided annotations and semantic tagging, in structured form, will enhance and improve eventful astronomy research and worldwide astronomical knowledge.
Responding to Big Data in Science

• **X-Informatics** (e.g., X = Bio, Geo, Astro, …):
  – addresses the scientific data lifecycle challenges in the era of Big Data and data-intensive science …
  – via data science techniques for indexing, accessing, searching, fusing, integrating, mining, and analyzing massive data repositories.
  – Includes automatic (autonomous) tagging and annotation

• **Citizen Science** (user-guided, informatics-powered):
  – Human computation (e.g., tagging, labeling, classification)
    • characterized by enormous cognitive capacity and pattern recognition efficiency (carbon-based computing)
  – Semantic e-Science **and** Volunteer Citizen Science
  – Tagging everything, everywhere: **Analytics in the Cloud**
Astroinformatics and Citizen Science: Resistance is futile, you will be assimilated.