Network Tools for Astronomical Data Retrieval

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ABSTRACT

The first step in a science project is the acquisition and understanding of the relevant data. This paper outlines the results of a project to design and test network tools specifically oriented at retrieving astronomical data. The tools range from simple data transfer methods to more complex browser-emulating scripts. When integrated with a defined sample or catalog, these scripts provide seamless techniques to retrieve and store data of varying types. Examples are given on how these tools can be used to leapfrog from website to website to acquire multi-wavelength datasets. This project demonstrates the capability to use multiple data websites, in conjunction, to perform the type of calculations once reserved for on-site datasets.

Subject headings: galaxies: evolution – galaxies: elliptical

1. INTRODUCTION

In the philosophy of science there is espoused a view that science moves in revolutions (Kuhn 1962), abrupt changes in the framework of scientific understanding in particular fields. Historical examples are global theories such as atomism and relativity. Under this concept of how science is done, between revolutions (or paradigm shifts) researchers are involved in 'puzzle-solving' type of science (normal science) attempting to stretch the limits of the current paradigm. New extremes pose problems for the current paradigms and leads to the next shift.

However, this view of science ignores a critical component to science, discovery. It is fair to say that most of our critical ideas in astronomy over the past few decades were not due to a paradigm shift or puzzle-solving science but rather due to discovery (e.g., dark matter, dark energy, quasars, Butcher-Oemler effect, etc.). It’s also becoming obvious that few of our theoretical ideas (computer models and simulations) are relevant beyond a few decades, but our discoveries last forever.

We (the astronomical community) are entering a new era of discovery science with the advent of all-sky, multi-wavelength, spectrophotometric and imaging archives. Later generations will look back on this time as a golden age for astronomy where new technologies and space missions opened regions of the electromagnetic spectrum previously unexplored. In fact, the current primary inhibitor to discovery science is our ability to search, sort and analyze our datasets.
During the 20th century, solid scientific progress was led by a combination of new technologies plus the computational power to analyze the output from these new technologies. Numerous are the published papers where a discovery hinged on some software tool or computational method to interpret the data. In addition, the turn of the century saw a sharp change from proprietary datasets to public domain, widely distributed datasets, and the new paradigm where one’s ability to search, query and understand the growing datasets defines the science to be done.

For many projects, the successful achievement of their science goals depends on their ability to perform e-science, the capability to gather and analysis the appropriate data. To this end, network tools, tools that enhance a researchers ability to gather data from networked sites, have become an increasing important weapon in a researchers arsenal. Discoveries by exploration of parameter space first require the samples be defined, then acquired. The new breed of researcher understands datasets, and how to gather the data.

2. Network Tools

All the tools developed for this project use the Python scripting language (www.python.org). Python has the advantage of being 1) easy to learn, 2) available on all operating systems (thereby, any scripts you write are easily transportable from system to system) and 3) contains numerous modules designed specifically to handle network issues. A scripting language also has the advantage of lacking a compiler, thus, it is easy to operate and flexible to work with. The Python language also has the unique characteristics of being well designed to work with text based data as well as numerical data, handles files and directories with little effort and enjoys an excellent try/except failure mode which is robust from errors that may cause a script to crash.

The reader is assumed to be mildly familiar with the Python language for this article is not a tutorial in Python usage (there are many on the web). However, the typical user will have no trouble building on the many examples provided by this project, while at the same time advancing their knowledge of the Python language. In addition, several Python software projects are found within the astronomical community (e.g. PyFITS, PyIRAF, Numpy, SciPy), and there is a growing number of modules to work with data, images, GUI’s, etc. Thus, there are many avenues for a researcher to quickly jump in and starting coding.

Much of the work described herein is an offshoot of the author’s ARCHANGEL galaxy photometry system (abyss.uoregon.edu/ js/archangel). That system found it useful to 1) pull the imaging data from some website archive (e.g., HST, 2MASS, DSS), 2) analysis the raw image and backup the results up to a separate system and 3) retrieve from NED (NASA’s Extragalactic Database) all the relevant information for calibration (e.g., galactic extinction, redshift, etc.). Each of these steps required the use of some script that could access data across the network and/or transfer files from place to place.

In the interest of generating a new network tools community, all the scripts discussed in this paper
are available for download from abyss.uoregon.edu/js/network. I sincerely hope that the reader finds them useful, learns, modifies them and, most importantly, sends me (jschombe@uoregon.edu) feedback on what works (and what broke) as well as ideas for future tools and research direction. This follows the model of a virtual community for computing knowledge.

3. Data Transfer by SSH/SFTP

Perhaps the most common method of file transfer and retrieval is sftp (secure shell file transfer protocol) using some version of OpenSSH protocols. This is certainly the most popular method of transferring data from one friendly system to another (friendly meaning you control both systems; e.g., transfer of data from the telescope to your office computer). A script that uses sftp would take the place of time consuming command line typing and, using Python’s ability to search and parse file directories. Even a small script eases the laborious typing required to transfer a mixture of file types.

The simplest manner to communicate to the shell from Python is the use of the `os.system` command (although the much more complicated `subprocess` module is now recommended). The following example pushes a bunch of FITS files onto a remote system by making a temporary file with sftp commands, then uses `os.system` to send a 'sftp -b' commands to the shell.

```python
import os
file=open('sftp.cmds','w')
file.write('cd /data')
file.write('put *.fits')
file.write('quit')
file.close()
os.system('sftp -b sftp.cmds user@some_data_site')
os.system('rm sftp.cmds')
```

This type of operation works well as a cron job for moving backup files during off hours, or any background task that doesn’t require human monitoring. However, this type of script is clumsy (e.g., requires the creation and destruction of the temporary file, `sftp.cmds`). A smoother interface uses the `pexpect` module (sourceforge.net/projects/pexpect), as in the following example:

```python
import pexpect
p=pexpect.spawn('sftp user@some_data_site.edu')
p.expect('sftp>')
p.sendline('cd /data')
p.sendline('put *.fits')
p.sendline('quit')
```
Also note that both scripts require a connection with the host that uses a 'no password' public key (easy to step up for machines you own). If the script requires a password, you will be prompted for it (thus, failing for a cron job). Automatic passwords are more difficult in scripts as they must come from pty rather than stdin. And that information is too powerful for this paper.

Simple transfers seem the least necessary to automate. If one controls both systems, the transfers are not time critical. However, one can imagine scenarios where scripts of this type may be useful. For example, one could run a script in background, say every 5 minutes, that identifies recent data, and ships it down range to avoid loses from catastrophic failures at one end (e.g., telescope computer hard drive failure).

4. Data Transfer by URL’s/HTTP

By the 1990’s, the standard method of distributing data was through the use of websites. In fact, for a majority of projects mandated to distribute data, a webpage is the fastest technique to comply to the requirements. A remote system interacts with websites through the use of URL’s (uniform resource locator). Access through URL’s is the responsibility of the urllib module in Python. This module allows a script to send a request to a website, read the return HTML file and store in memory. A simple example is the following:

```python
import urllib
page=urllib.urlopen('http://a_webpage.com').read()
```

Of course, the returning data is the HTML that makes up the webpage, which is usually not the most transparent format for extracting data. Parsing the HTML to extract a value can be tricky, although there are modules for extracting tabular data (e.g. BeautifulSoup, www.crummy.com/software/BeautifulSoup). A simple command to strip all the HTML commands uses the regular expression (re) module (i.e., `re.sub('<.*?>','',page)`). This will leave you with all the words and numbers outside the hypertext tags. It’s also possible to identify specific pieces of information in a webpage. For example, a favorite comic strip image by searching on "src img=" tag, then stripping the identifier tag.

Again, using an urllib script as a cron job allows a user to monitor websites for changes or new data. The user can be alerted by email using the smtplib module, where the script can email a message through an approved SMTP server (see example below). This is particular useful for time critical information (sudden change in your bank account? opening in a class you want to attend?).

```python
import smtplib
server=smtplib.SMTP('smtp.gmail.com')
msg='Content-Type: text/html

Subject: Automatic Email

<html><pre>
A message!
</pre></html>

server.sendmail('mail_bot@your_machine','user@gmail.com',msg)
server.quit()
```
Some websites maintain a consistency to their HTML format such that quick information can be extracted with a simple script. For example, the following script grabs the J2000 coords for a galaxy from NED:

```python
import urllib, sys
name=''.join(sys.argv[1:])
page=urllib.urlopen('http://nedwww.ipac.caltech.edu/cgi-bin/nph-objsearch?'+'objname='+name+'&extend=no&out_csys=Equatorial'+'&out_equinox=J2000.0&obj_sort=RA+or+Longitude'+'&of=pre_text&zv_breaker=30000.0&list_limit=5'+ '&img_stamp=YES').read()
for t in page.split('
'):
    if 'Equatorial' in t and 'J2000' in t:
        print ' | '.join(t.split()[:6]),'|'
        break
else:
    print 'object not found in NED'
```

Note that the object name is all the words after the command (e.g. `./ned.py NGC 4881`). The parsing is done by NED, the webpage is piped back to the script. The script then splits by carriage returns looking for the line that has the coordinates. The secret here is that NED always maintains the same 'look', and the coordinates are always on the line with unique identifiers 'Equatorial' and 'J2000'.

Again, this is not an elegant method to communicate with a data archive, but it is the simplest. Some investment in time is spent decoding the source hypertext of the webpage to find the particular set of lines from which to extract the values. Thus, this method is hardly efficient if one needs more information than a simple set of coordinates.

To capture the full collection of data on a galaxy, NED offers an XML output to their queries. In order to access the XML file, one simply changes the URL by adding "of=xmlall". This returns the entire set of NED data on the query galaxy in an easy to parse XML format. NED also offers several XML files for photometry data, reference data, etc (see the tools website for a suite of NED scripts). To work with the returning XML file, Python has a number of XML modules. However, this project has constructed one that better matches astronomical data and is discussed in the next section.

5. XML processing

Storage of data in XML format closely mimics the HTML format that make up webpages through the use of tags to identify each data element. Each element (or data atom) has attributes, data and
children associated with it. For example, an element ‘redshift’ may have the data value of 35,444 and an attribute of ‘units=km/sec’. Children are addition elements embedded inside the parent element. XML files are not particularly readable, but as they are stored in raw ASCII format and are, therefore, very transportable.

To ease the conversion of data into XML format (and its extraction), this project offers an XML module (xml.archangel) based on Python’s xml.dom routines. This module was designed for storage of galaxy photometry data; however, is flexible to accommodate any type of data as well as arrays. The module offers two basic classes, xml_read and xml_write. The xml_read class takes a standard XML file and parses into a Python list of elements using the following commands:

```python
from xml_archangel import *
doc = minidom.parse(file)
rootNode = doc.documentElement
elements=xml_read(rootNode).walk(rootNode)
```

The resulting list, `elements` is packaged into three parts, its attributes (as a dictionary), its data and its children (also as a dictionary). Thus, each element appears in the script as the following:

```
[{attributes},data,{children}]
```

Using the standard Python notation, the attributes and children of an element are in the form of a dictionary, the data are a unicode string. The children elements, of course, are stored in the same structure, which allows recursive searching for nested elements. Note that this element list can be modified by the script, then output to a file with the xml_write call. The xml_archangel script allows the user to pull or push elements into an XML file, add arrays or print a tree of the entire list.

Arrays are handled in a slightly different fashion. Following the recommendations of the VOTable project, arrays are stored as element name ‘array’ (attributes that indicate the name of the array) with each array having N children called ‘axis’. For example, an array of sky box positions:

```xml
<array name='sky_boxes'>
    <axis name='x'>
        45
        65
        33
    </axis>
    <axis name='y'>
        23
        55
```
While this is not the most readable format, it is easy to parse in a Python script. The script can then convert this into a numerical array for processing with the extremely useful numpy routines (http://numpy.scipy.org) that bring all the power of a C++ processing routine into Python.

6. Image Extraction (DSS/2MASS)

Most of the common data archives use a simple POST/GET webpage to access their data using HTML FORM methods. One example is the DSS archive (archive.stsci.edu/cgi-bin/dss_form) where the user enters a name or coordinate of interest and selects the type of Palomar Sky Survey image to be downloaded. Standard HTML FORM stores the user selected variables (in the source webpage as "input" tags) and passes them into a new URL with the variables in the format of "&variable=value". So the user can use the webpage to enter the variables or, if they know the variable names, they can simply type the URL themselves.

Any website that uses a HTML FORM can be parsed into a URL for a Python script. Some detective work is needed, for example, searching through the source to identify all the variables. Or the user can make a simple search, then copy/paste the URL from the navigation bar on their browser into the Python script (noted what variables control the object). There are also tools available in the common browsers to diagnose a webpage (e.g., the Web Developer add-on in Firefox).

The examples at our project website list two scripts (too long for this article, although only 50 lines in total length), one to access DSS images from STScI and the other to extract images from 2MASS. Both take advantage of NED’s website to find a galaxy’s coordinates, parse a URL using those coordinates (and user selected field size, image type, etc.) then upload that URL to DSS/2MASS ("squirt the bird" in NASA terminology). The script then reads the return data stream and writes out a FITS file. Slight modification to the script allows images to be stitched together, or multiple bandpasses to be built into a hypercube.

This is a good point in our discussion to mention abuse. These scripts are indented for use on small samples (less than 50 or so). Downloading, for example, the entire UGC catalog from DSS is not an efficient use of network time. For extremely large samples, the user is encouraged to contact
the project in question for extraction of the needed data on-site. The projects are always helpful working with large projects, and collaboration with the projects for this type of research sends a strong message to the funding agencies. Bottom line, use some common sense in the amount of data you are requesting from websites intended only for the exchange of a few images at a time.

### 7. Cookies and Passwords

More sophisticated websites require passwords and use cookies to prevent a user from spoofing the URL directly to the data. Python also has the ability to store cookies in an automatic fashion using the `httplib` module. A typical interaction with a website with a password and session cookie would look like the following:

```python
import httplib, urllib
userid='joe_user'
password='a_password'
urlencoded = urllib.urlencode({'user': userid, 'pin': password})
hlink = httplib.HTTP('the_website.com')
hlink.putrequest('POST', '/the_area_of_interest')
hlink.putheader('Cookie', 'SESSION_ID=set')
hlink.putheader('Content-type', 'application/x-www-form-urlencoded')
hlink.putheader('Content-length', '%d' % len(urlencoded))
hlink.endheaders()
hlink.send(urlencoded)
errcode, errmsg, header = hlink.getreply()
if errcode == 503:
    print 'website off-line'
sys.exit()
mark=str(header).index('Cookie')
cookie=str(header)[mark+15:mark+31]
page=hlink.getfile().read()
```

In this example, every further page request requires a new `hlink.putrequest('GET', 'new_place')` and a new cookie is sent by the website to be tested for the next page request. Note that the user must have a legitimate ID and password, this is not a technique to hack a website and it is assumed the user has authorized access to the data.

The uses for this type of script are endless. Written as a cron job, this routine can monitor your bank account, credit card, class lists or grant proposals. Again, when matched with the `smtplib` module, such a script becomes a powerful email alert system.
Another use for a script of this type is the automatic submission of data. For example, my University requires that student grades be entered into a website using drop-down menus for each student ID. If the class contains 200 students, this can literally be a several hour activity. Instead, a short script can be written to login into the website, grab a file of student grades on the local machine and POST them to the website by student ID (although your local network services might be curious on how you entered 200 grades in 3.5 microseconds). Again, this technique is open to abuse and a responsible user would limit the number of interactions with a website, and their frequency (e.g., placing the `time.sleep(1)` command between page requests).

8. Behaving like a Browser

Websites have become increasingly complex in recent years, often with complicated cookies that the `urllib` and `httplib` modules fail to handle. However, every website must interact with a browser, so nothing can be encoded or hidden that can’t be parsed by whichever browser the user selects. Ultimately, the best script is one that behaves like a browser and can be trained to proceed to the internal pages of interest (i.e. clicking the buttons). This is the job of the `mechanize` module (wwwsearch.sourceforge.net/mechanize).

There are numerous examples at the `mechanize` website, but the following is a simple use in a script:

```python
from mechanize import Browser
from mechanize import UserAgent
b = Browser()
b.addheaders=[('User-Agent','Python script')]
b.open('https://secure_website.com')
userid='user_id'
password='a_password'
b.select_form(name='LoginForm')
b['userID']=userid
b.submit()
for form in b.forms():
    print form
```

Note that the website may reject User-Agent’s that are not a known browsers. This script must be trained, in the sense that the user probably needs to manually follow the website paths first, then copy those paths into the script. And more detective work is probably required on the FORM variables and their usage.

The ultimate goal for a script that uses mechanize is to parse and understand what a webpage means, and use that information to make decisions. This would form the front end of a thinking
or knowledge system, one that harvests information at a higher level than just reducing the data from tabular form. This will be the focus of our future work.

9. Summary

The goal of this paper is to outline some simple network tools to enhance the retrieval of astronomical data from local machines or data archive websites. Hopefully, these scripts improve the efficiency of a researchers to find and acquire the information they need to address their science questions. Less time spent managing files and directories means more time spent on analysis and understanding.

Some examples of uses for these scripts are:

- Transfer of backup files during off hours by cron jobs
- Monitor files and submit email alerts for multiple systems
- Retrieve and parse a webpage
- Extract a value from a webpage
- Submit a request and respond from a webpage
- Pull XML data from a webpage
- Interact, in an automatic fashion, with a website that uses a ID/password
- Behave like a browser, parsing requests and designing responds interactively with a website

The reader is invited to modify or add to the network library. Simply send your comments and scripts to jschombe@uoregon.edu and we will post them on the growing website.

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