Geospatial Programming in Python

Tony Castronova
Utah State University

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Learning Objectives

1. Understand the benefits of extending ArcGIS through programming
2. Introduce Python programming basics
3. Understand how to collect data using web services
4. Demonstrate how to build a Python script that uses ArcMap tools

Suggested Reading

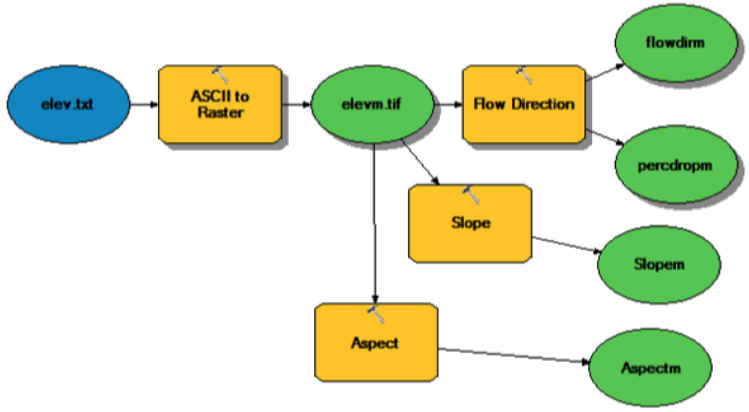
Using ArcMap Functions
http://resources.arcgis.com/en/help/main/10.1/index.html#/Using_functions_in_Python/002z0000000m000000

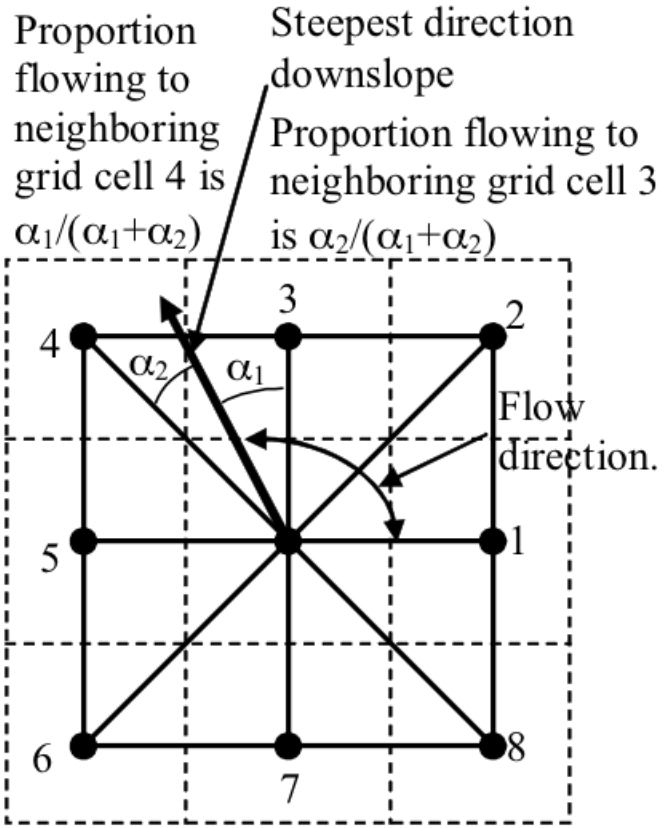
Using Python Classes
http://resources.arcgis.com/en/help/main/10.1/index.html#/Using_classes_in_Python/002z0000000s000000/

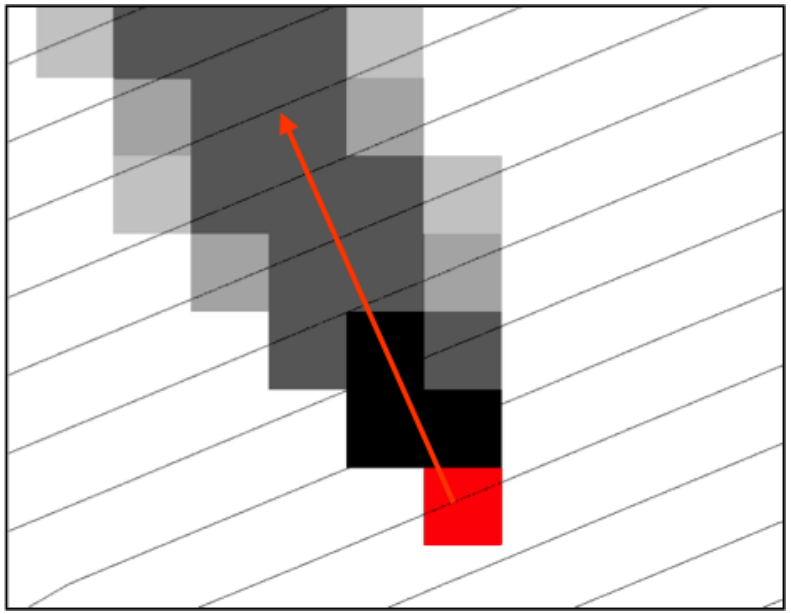
Accessing ArcGIS Licenses http://resources.arcgis.com/en/help/main/10.1/index.html#/Accessing_licenses_and_extensions_in_Python/002z0000000z000000/

Why Programming?

- Automation of repetitive tasks $\rightarrow$
- Implementation of functionality that would not otherwise be available $\downarrow$

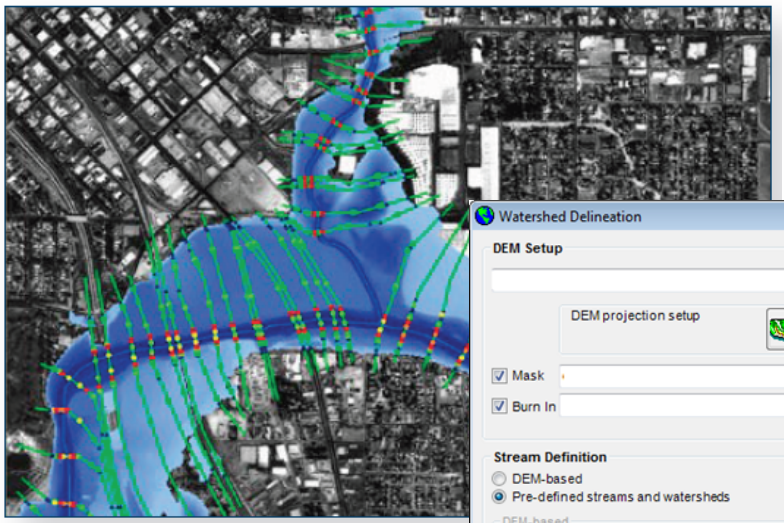


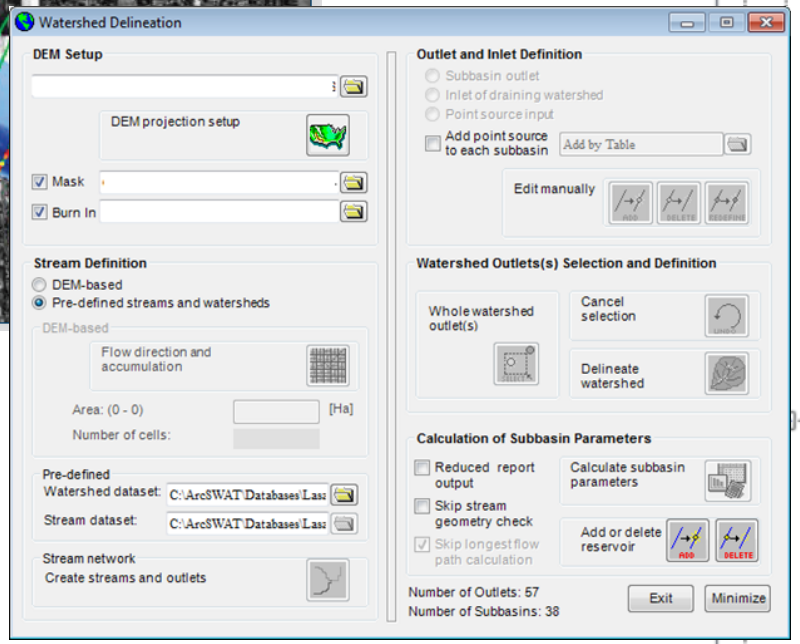


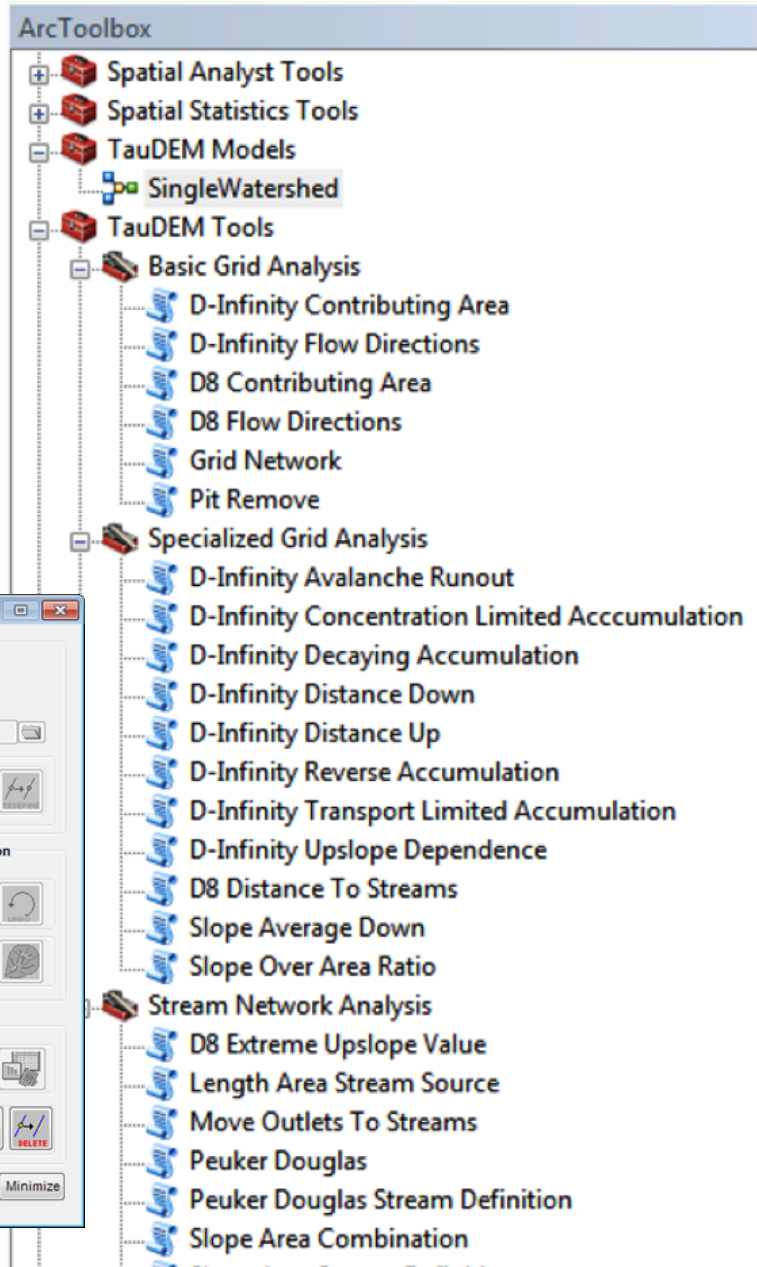


Extending ArcGIS

- TauDEM
- ArcSWAT, *Soil and Water Assessment Tool*
- Hec-GeoRAS, *River Analysis System*
- etc ...



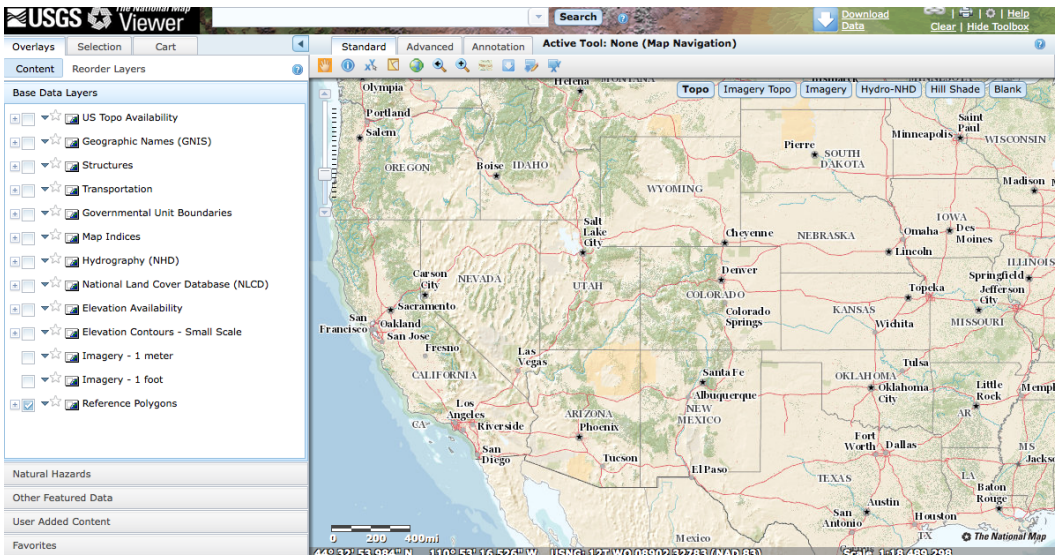


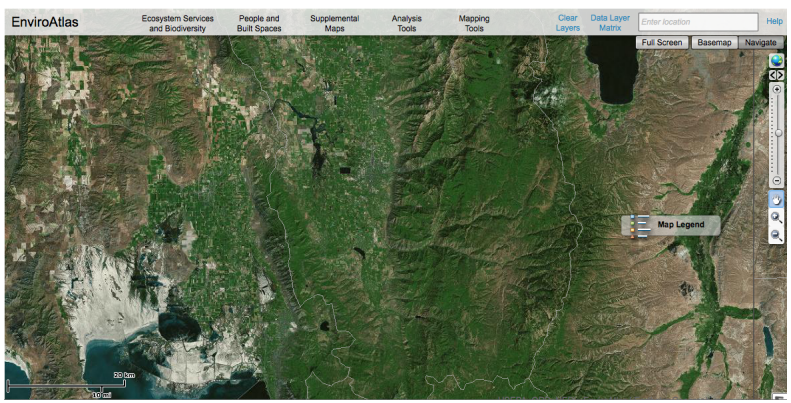


Workflow Automation

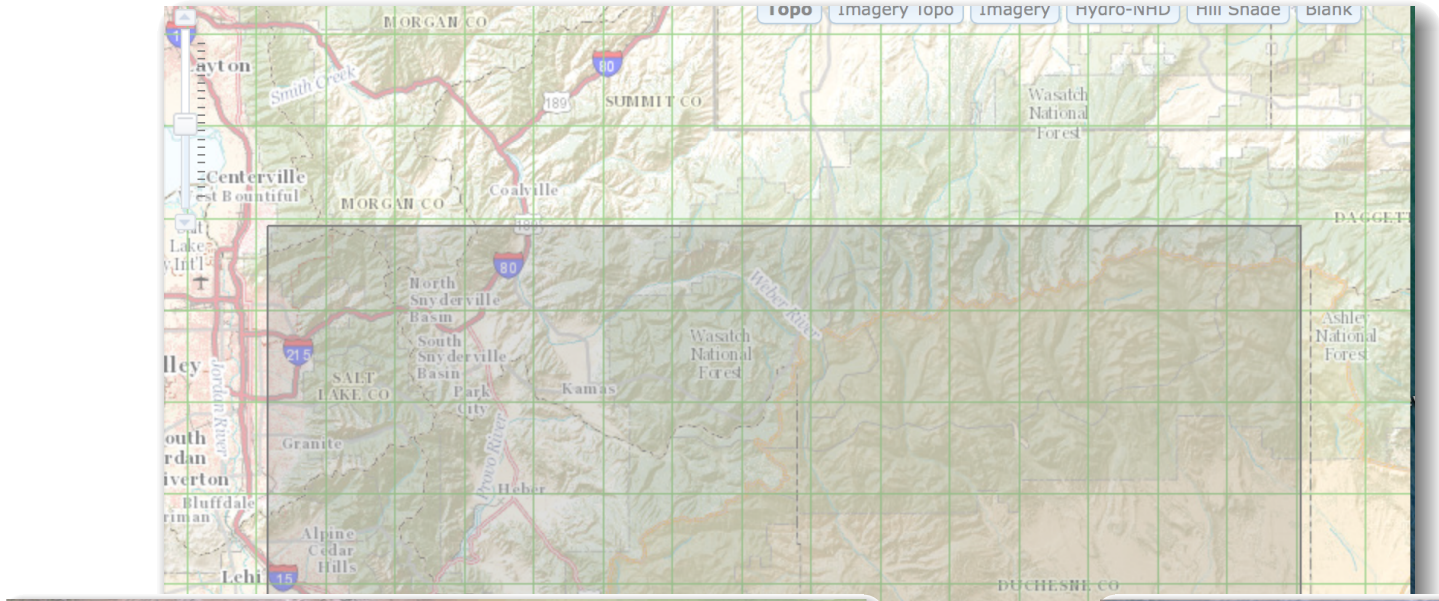
Lets Consider Data Collection

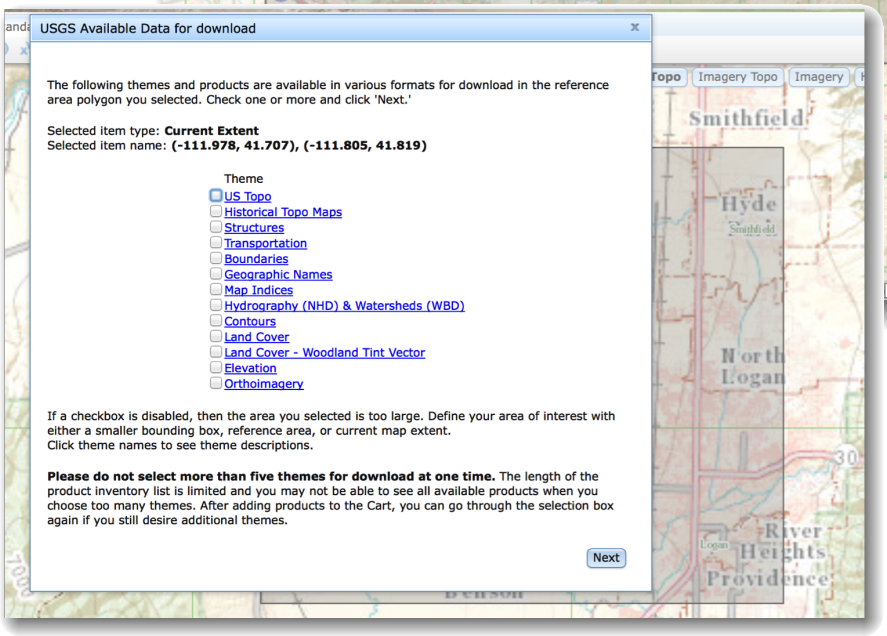
- United State Geological Survey, USGS
- Interactive map selection
- Tiled Data
- Emailed links to download datasets

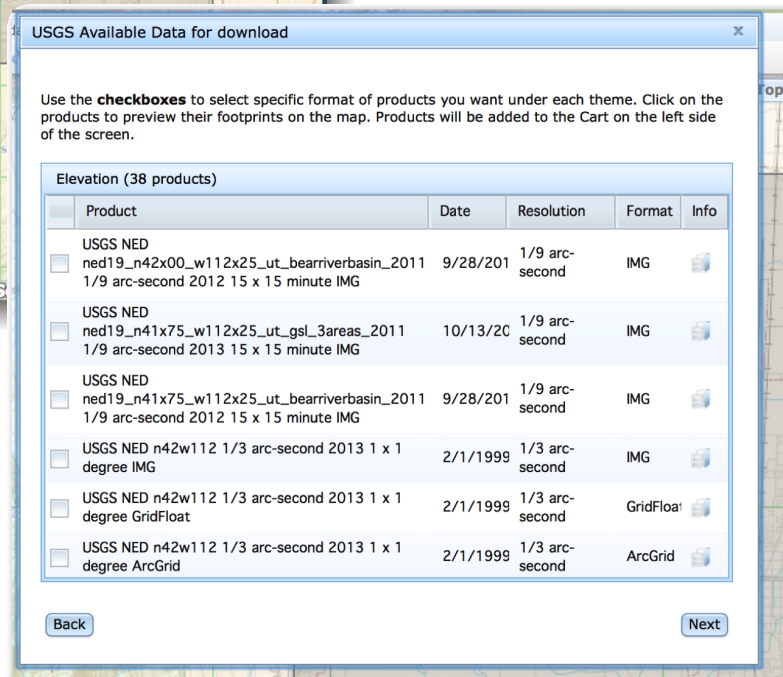




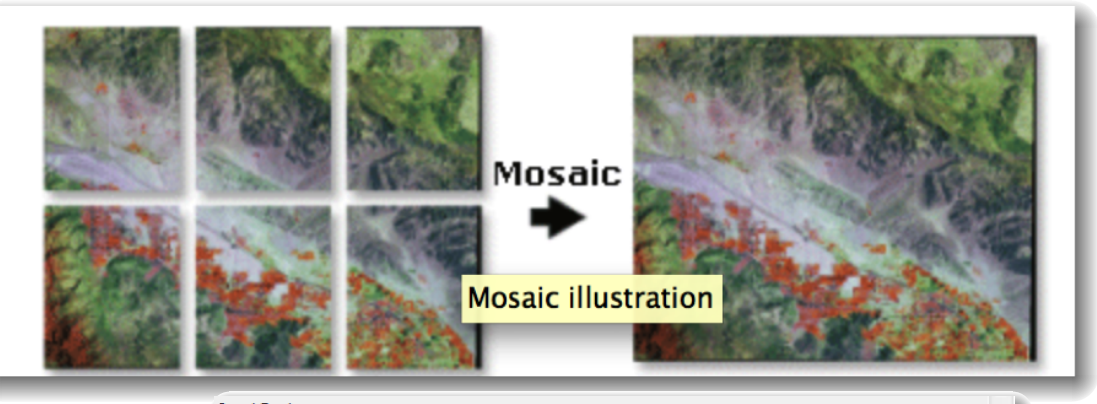
Downloading Data from the National Map Viewer

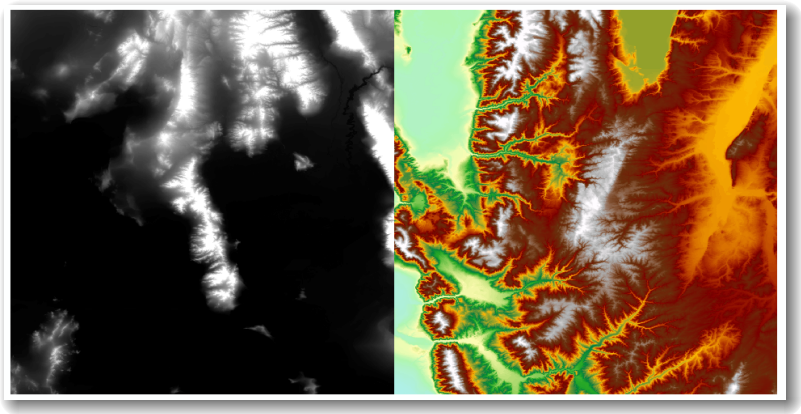


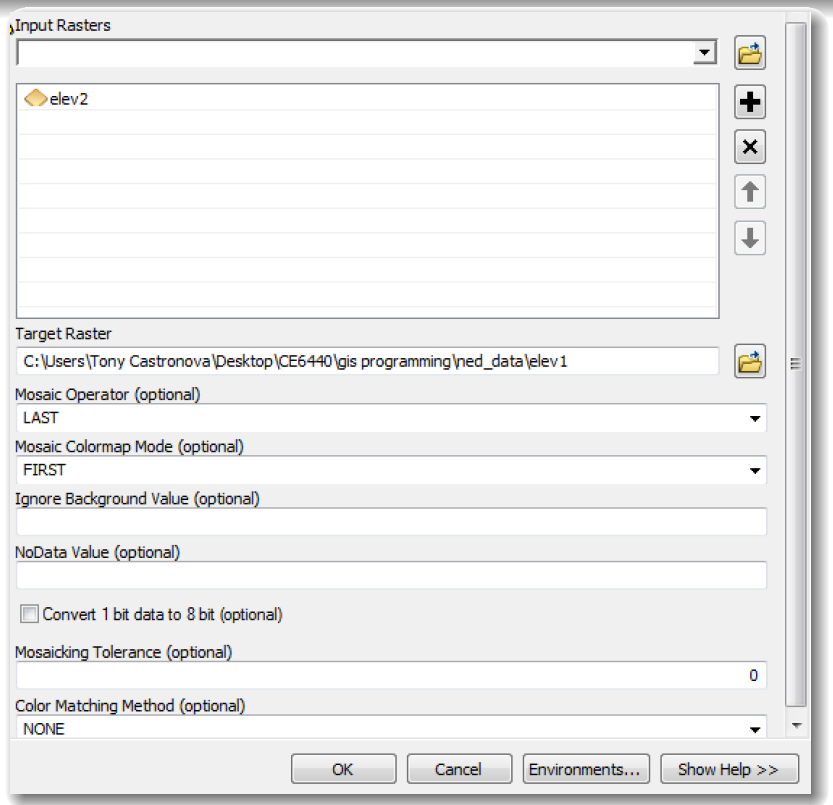


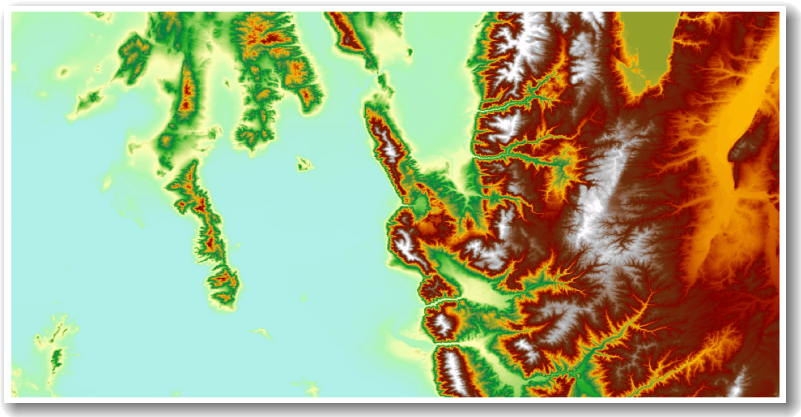


ArcGIS Processing









Shortcomings of this Approach

Shortcomings

- Manual process (e.g. following documentation/tutorial)
- Difficult to share workflows with others
- Time consuming and tedious
- Repetitive
- Not feasible for large datasets

Solution

- Build tools
- Write scripts
- Use web services

Introduction to Programming

- Set of the instructions that direct the computer to perform certain tasks
- User input and output
- Mathematical representations and algorithms
- Logical structure (sequence, repetition)
- Modular design
- EXCEL/VBA, Matlab, Maple, Mathematica
- Fortran, C/C++, .NET, Ruby, Perl, Python

Programming Logic/Control

```
IF <condition> THEN
    true block
ENDIF
```

```
if i % 2 == 0:
    print 'i is even!'
```

```
IF <condition> THEN
    block 1
ELSEIF <condition>
    block 2
ELSE
    block 3
ENDIF
```

```
if i % 2 == 0:
    print 'i is even!'
elif i % 2 == 1:
    print 'i is odd'
else:
    print 'i is a float'
```

```
DO
    block 1
IF <condition>
    exit
ENDIF
```

```
while 1:
    i += 1
    value *= i
if i > 10:
    break
```

```
DOFOR i = start, finish, step
    block
ENDDO
```

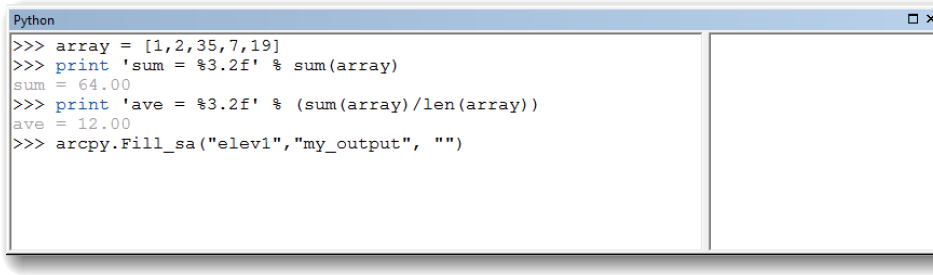
```
for i in range(0, 10, 1):
    print 'Hello'
```

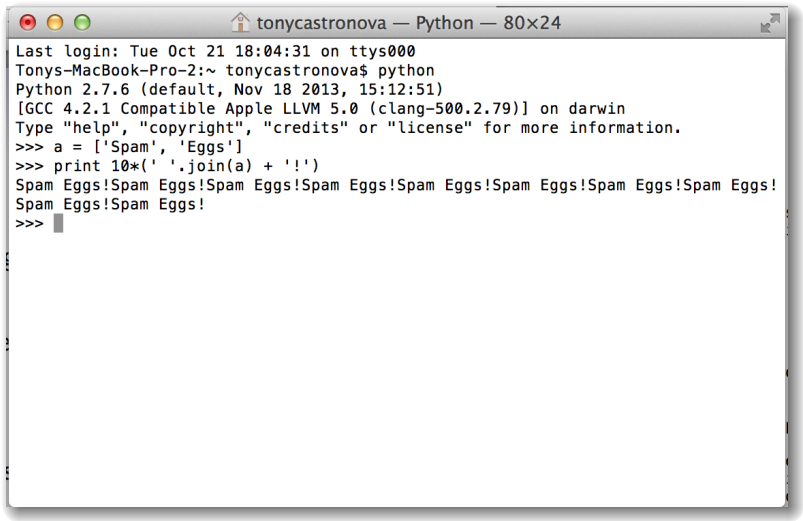
Example

```
1   def quadratic(a, b, c):
2
3       # calculate the discriminant
4       d = b ** 2 - 4 * a * c
5
6       if d < 0:
7
8           print ("This equation has no real solution")
9
10          # return the answer
11          return (None, None)
12
13      elif d == 0:
14
15          x = (-b+math.sqrt(b**2-4*a*c))/2*a
16          print ("This equation has one solutions: "), x
17
18          # return the answer
19          return (x,None)
20
21      else:
22
23          x1 = (-b+math.sqrt((b**2)-(4*(a*c))))/(2*a)
24          x2 = (-b-math.sqrt((b**2)-(4*(a*c))))/(2*a)
25          print ("This equation has two solutions: ", x1, " or", x2)
26
27          # return the answer
28          return (x1, x2)
```

What is Python

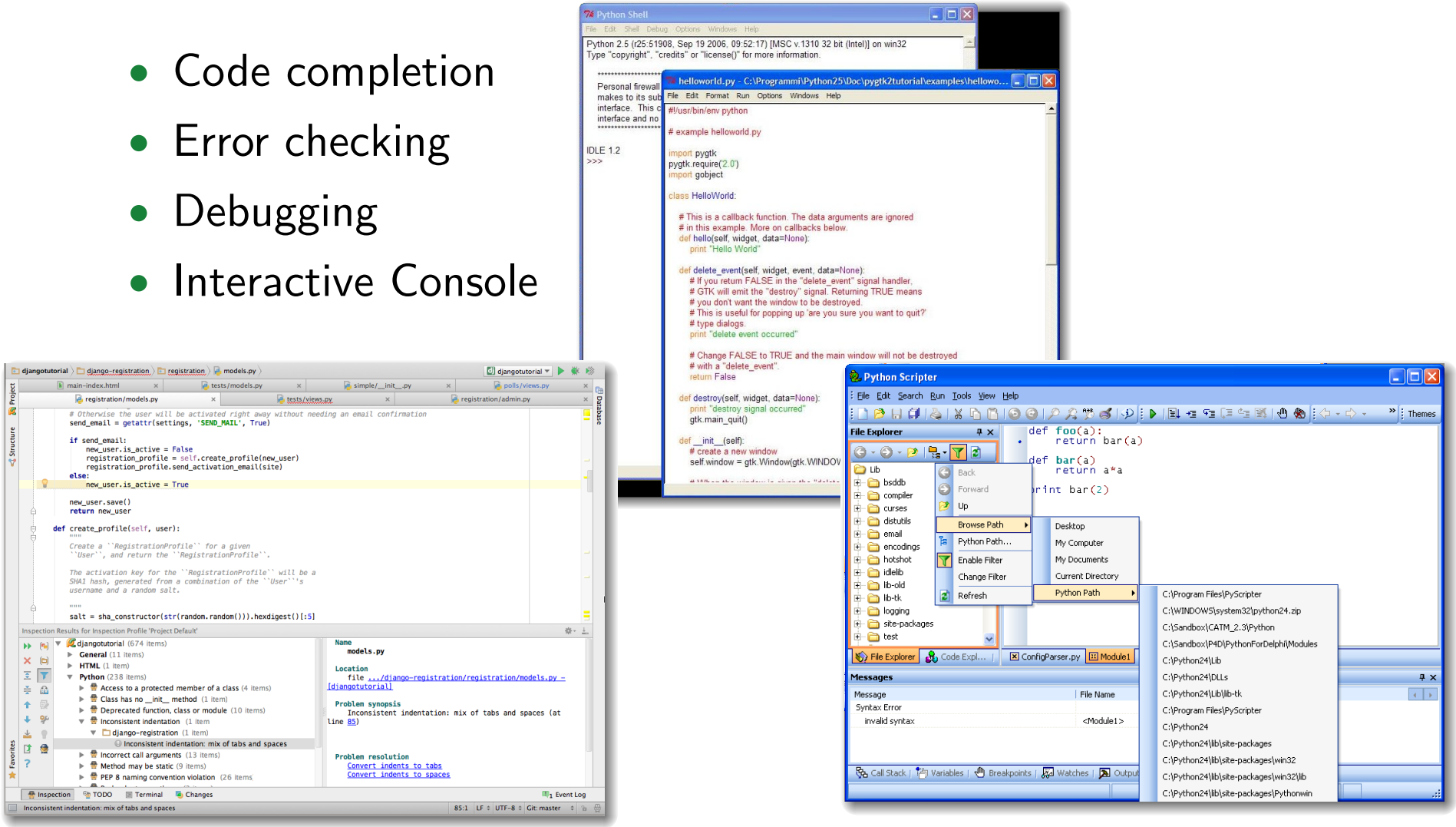
- Interpreted programming language
- Built from C
- Platform Independent (unlike .Net)
- Relatively lightweight
- No need to compile
- Many different versions (latest 3.4.2, most used is 2.7.8)
- ArcGIS already installed it!
- Execute tools inside ArcMap
- Execute tools/code using CMD/Terminal/Console
- Many Interactive Development Environments





Interactive Development Environments

- Code completion
- Error checking
- Debugging
- Interactive Console



https://wiki.python.org/moin/IntegratedDevelopmentEnvironments

(Very Brief) Introduction to Python, pt1

- General purpose programming language
- Indenting matters
- Duck typing (not type specific)
- Core data types

Object Type	**Example**
Numbers	1234, 3.1415
Strings	'spam', "eggs"
Lists	[1, 2, 3], [1, ['spam', 'eggs']]
Dictionaries	'food':'spam','taste':'yum'

```
# this is a type double
my_variable = 10.123

# now its a string
my_variable = 'some string'

# now its a list
my_variable = [1,2,3,4,5]
```

http://www.codecademy.com/courses/introduction-to-python-6WeG3/

https://docs.python.org/2/tutorial/

(Very Brief) Introduction to Python, pt2

```
import os
import sys
import numpy
import suds
```

- Import statements
- Control statements
- Functions
- Classes

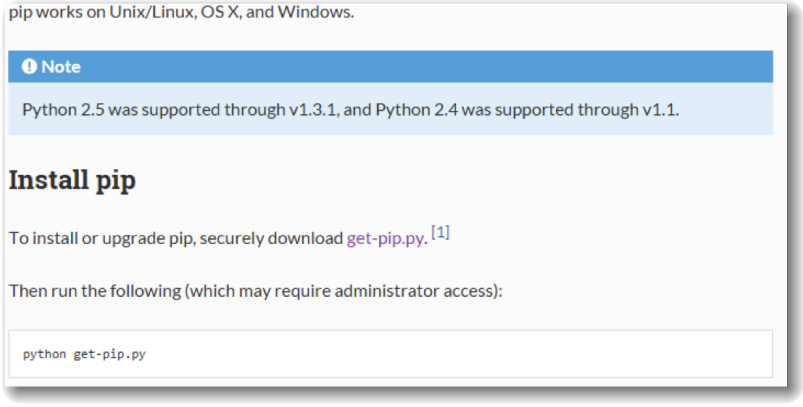
```
for i in range(0,10):
    # do something

while i == True:
    # do something
    if i == False:
        break

while 1:
    # do something
    if condition:
        break
```

```
class MyClass():
    def __init__(self):
        d = 1

    def some_calc(self, a, b, c):
        d = d + 1
        return d + (a * b + c**2)

# create instance of MyClass
mycalc = MyClass()

print mycalc.some_calc(1,2,3)
# 13

print mycalc.some_calc(1,1,2)
# 7
```

```
def myFuction(a, b, c):
    # do something
    some_calc = a * b + c**2

    # return the result
    return some_calc
```

Package Management

- Enables you to extend Python's native functionality
- Using 3rd party libraries, e.g. ArcGIS
- PIP


pip works on Unix/Linux, OS X, and Windows.

Note

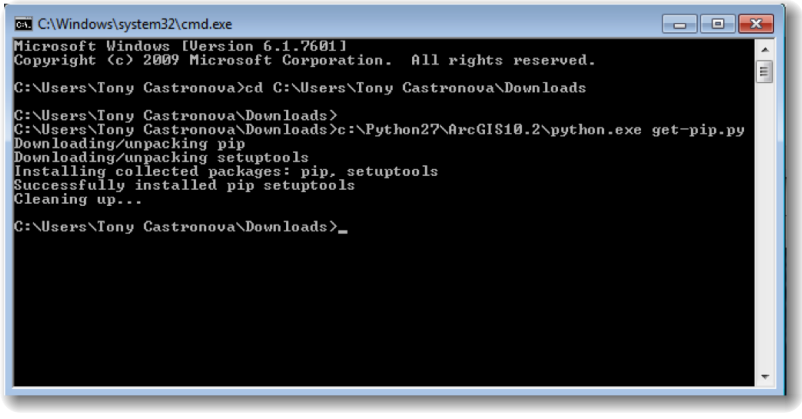
Python 2.5 was supported through v1.3.1, and Python 2.4 was supported through v1.1.

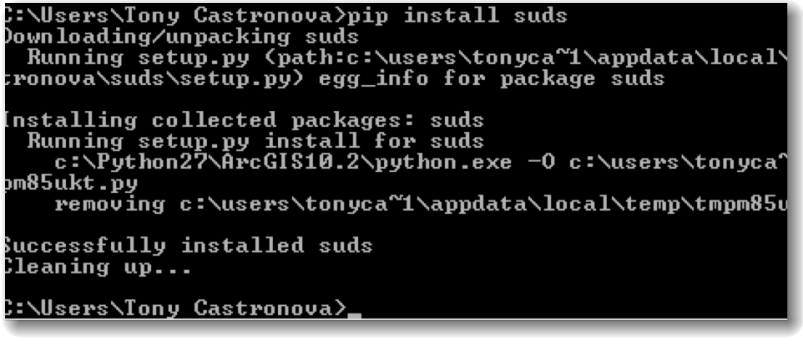
Install pip

To install or upgrade pip, securely download get-pip.py. [1]

Then run the following (which may require administrator access):

```
python get-pip.py
```

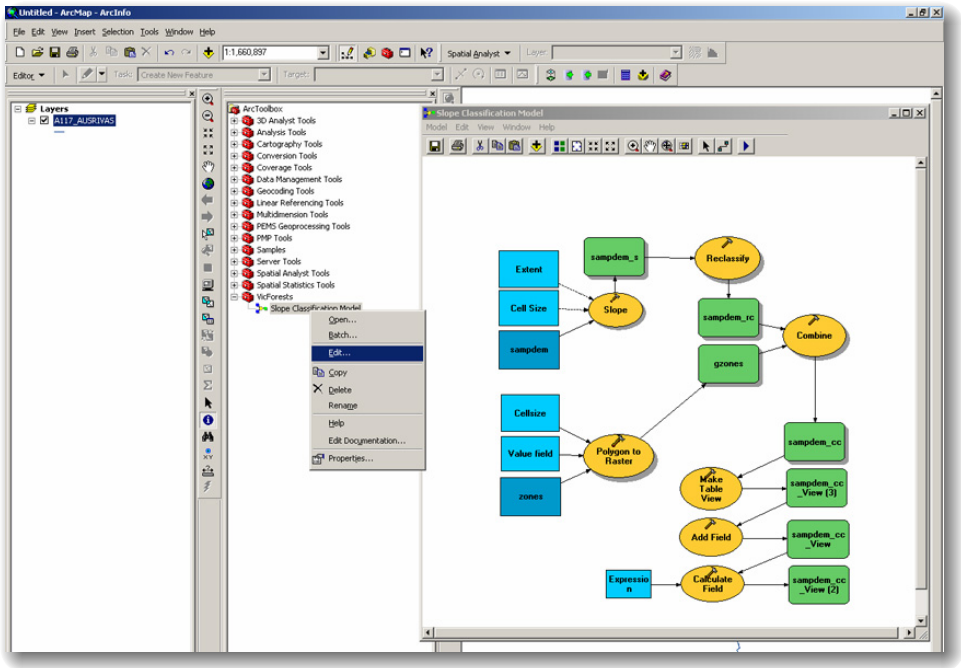




https://pip.pypa.io/en/latest/installing.html

ArcGIS Programming in Python

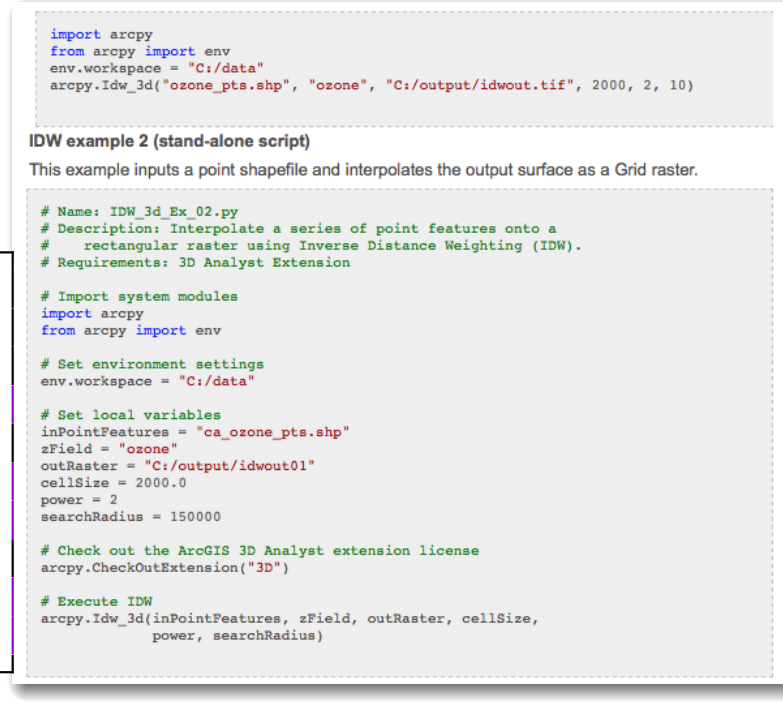
- ArcPy is the ArcGIS python module
- Provides a productive way to perform geographic data analysis using ArcGIS tools
- Organized into tools, functions, classes, and modules



ArcGIS Tools

- Every tool has its own reference page
- Tools produce results, while functions do not
- Tools produce messages
- Tools are licensed

```
import arcpy
arcpy.AddField_management("c:/data/Portland.gdb/streets"
    , "LENGTH_MILES", "TEXT")
arcpy.CalculateField_management("c:/data/Portland.gdb/
    streets", "LENGTH_MILES", "!shape.length@miles!", "
    PYTHON_9.3")
arcpy.FeatureClassToFeatureClass_conversion("c:/data/
    Portland.gdb/streets", "Database Connections/MySDE.
    sde/PortlandDataset", "streets")
```



```
import arcpy
from arcpy import env
env.workspace = "C:/data"
arcpy.Idw_3d("ozone_pts.shp", "ozone", "C:/output/idwout.tif", 2000, 2, 10)
```

IDW example 2 (stand-alone script)

This example inputs a point shapefile and interpolates the output surface as a Grid raster.

```
# Name: IDW_3d_Ex_02.py
# Description: Interpolate a series of point features onto a
#    rectangular raster using Inverse Distance Weighting (IDW).
# Requirements: 3D Analyst Extension

# Import system modules
import arcpy
from arcpy import env

# Set environment settings
env.workspace = "C:/data"

# Set local variables
inPointFeatures = "ca_ozone_pts.shp"
zField = "ozone"
outRaster = "C:/output/idwout01"
cellSize = 2000.0
power = 2
searchRadius = 150000

# Check out the ArcGIS 3D Analyst extension license
arcpy.CheckOutExtension("3D")

# Execute IDW
arcpy.Idw_3d(inPointFeatures, zField, outRaster, cellSize,
             power, searchRadius)
```

http://resources.arcgis.com/en/help/main/10.1/index.html#//002t0000000z000000

ArcPy Functions

- Small piece of functionality
- Incorporated into larger programs
- list datasets, retrieve properties, check for existence of data

```
import arcpy

# prints True
print arcpy.Exists("c:/data/Portland.gdb/streets")

# prints NAD_1983_StatePlane_Oregon_North_FIPS_3601_Feet
sr = arcpy.Describe("c:/data/Portland.gdb/streets").
     spatialReference
print sr.name

# prints Available
print arcpy.CheckExtension("spatial")

arcpy.CheckOutExtension("spatial")
```

ArcPy Classes

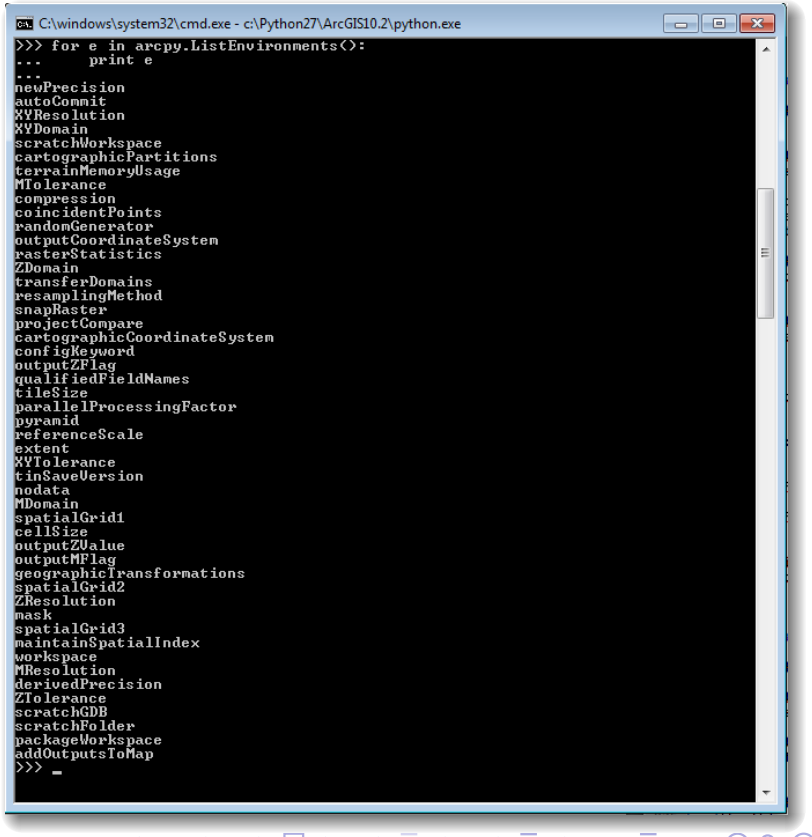
- Architectural blueprint
- Class objects are called instances
- Often used as shortcuts for completing a geoprocessing tool

```
import arcpy

inputWorkspace = "c:/temp"
outputName =  "rivers.shp"

prjFile = "c:/projections/North America Equidistant
    Conic.prj"
spatialRef = arcpy.SpatialReference(prjFile)

# Run CreateFeatureclass using the spatial reference
    object
#
arcpy.CreateFeatureclass_management(inputWorkspace,
    outputName, "POLYLINE",
                                    "", "", "",
                                        spatialRef)
```

ArcPy Environment Settings

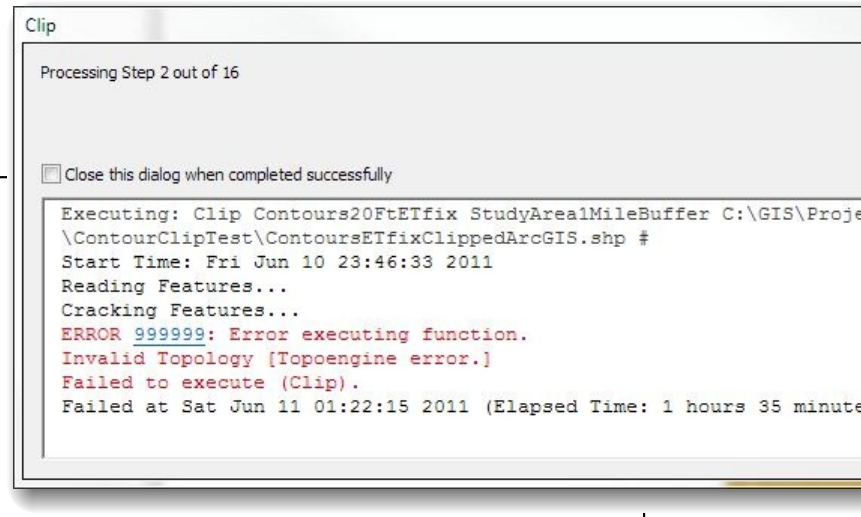
- Global settings
- Default values can be overridden
- nodata value, output spatial reference, cell size

```
import arcpy
from arcpy import env

# Check the current raster cell size and make
      sure it is a certain size
#    for standard output
#
env.workspace = "c:/avalon/data"

if env.cellSize < 10:
    env.cellSize = 10
elif env.cellSize > 20:
    env.cellSize = 20

arcpy.HillShade_3d("island_dem", "island_shade",
       300)
```



Error Checking

- Errors will cause your script to break/fail
- Error catching can prevent this (to and extent)
- Python try-except statements
- ArcPy message retrieval




```
import arcpy
from arcpy import env
try:
    if arcpy.CheckExtension("3D") == "Available":
        arcpy.CheckOutExtension("3D")
    else:
        raise LicenseError
    env.workspace = "D:/GrosMorne"
    arcpy.HillShade_3d("WesternBrook", "westbrook_hill", 300)
    arcpy.Aspect_3d("WesternBrook", "westbrook_aspect")
except LicenseError:
    print "3D Analyst license is unavailable"
except:
    print arcpy.GetMessages(2)
finally:
    arcpy.CheckInExtension("3D")
```

ArcPy Scripting, pt1

```
1   __author__ = "tonycastronova"
2
3   # Tony's ArcGIS script
4   # This is a demo for CEE 6440
5   # 10/22/2014
6
7   # Import system modules
8   import arcpy
9
10  # Set workspace
11  env.workspace = "C:/data"
12
13  # Set local variables
14  in_features = "majorrds.shp"
15  clip_features = "study_quads.shp"
16  out_feature_class = "studyarea.shp"
17  xy_tolerance = ""
18
19  try:
20      # Execute Clip
21      arcpy.Clip_analysis(in_features, clip_features, out_feature_class, xy_tolerance)
22  except Exception:
23      print 'Something went wrong :( '
24      for i in arcpy.GetMessageCount():
25          print i
```

- Establish the basic structure of the script
- Look on ArcGIS website for tool definitions
- Make sure this runs before we move on

ArcPy Scripting, pt2

```
__author__ = "tonycastronova"

# Tony's ArcGIS script
# This is a demo for CEE 6440
# 10/22/2014

# Import system modules
import arcpy
import os

# Set workspace
env.workspace = "C:/data"

# Set local variables
#in_features = "majorrds.shp"
clip_features = "study_quads.shp"
#out_feature_class = "studyarea.shp"
xy_tolerance = ""

# find all shapefiles in the current directory
directory_contents = os.listdir('.')
files = []
for item in directory_contents:
    if os.path.isfile(item):
        if item.split('.')[1] == 'shp':
            files.append(item)

# continued on next slide ...
```

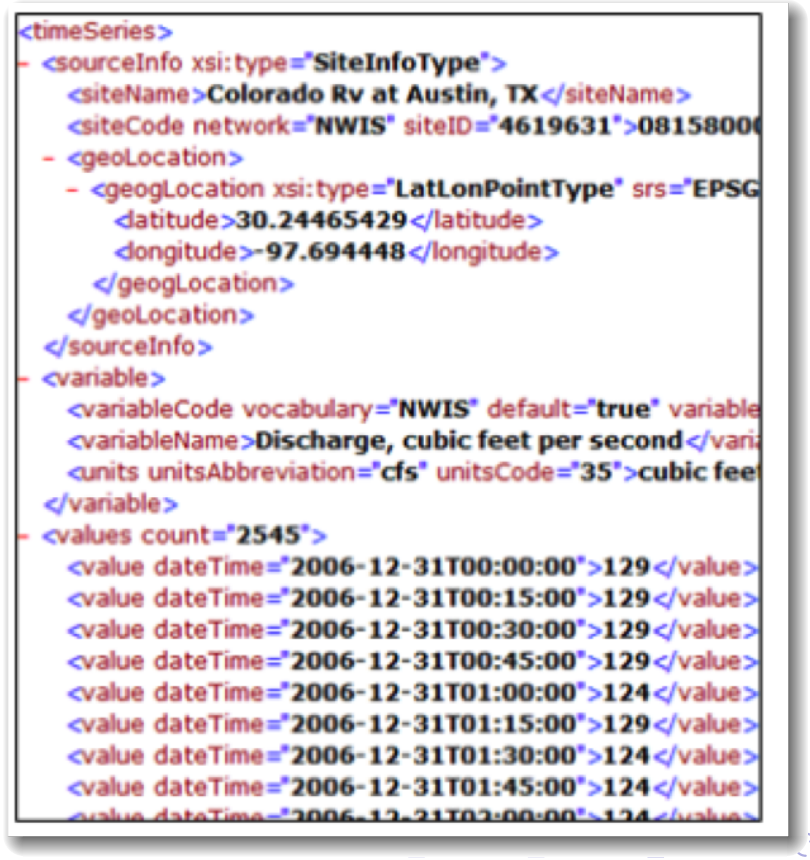
ArcPy Scripting, pt3

```
30  # loop over files in directory and clip
31  for file in files:
32      in_features = file
33      out_features = file.split('.')+'_clip.shp'
34      try:
35          # Execute Clip
36          arcpy.Clip_analysis(in_features, clip_features, out_feature_class, xy_tolerance)
37      except Exception:
38          print 'Something went wrong :( '
39          for i in arcpy.GetMessageCount():
40              print i
```

- This script provides an easy way to automate the Clip tool
- Could be used for clipping dependent datasets
- Could be extended to perform many tasks in sequence

Web Services

- Standardized communication between clients and web servers
- Several different standards. SOAP + WSDL, REST, XML-RPC
- XML-based protocols
- Can be used to gather data from national datasets



http://www.opengeospatial.org

What data is available?

- You can get any data that have webservices!
- USGS - streamflow, groundwater, water quality
- EPA STORET - water quality
- DAYMET - meteorological surface temperature, precipitation, humidity, etc.
- MODIS - surface temperature, snow cover, vegetation, etc.

`http://daymet.ornl.gov` `http://www.epa.gov/storet/dbtop.html`

`http://modis.gsfc.nasa.gov` `http://waterdata.usgs.gov/nwis`

`http://his.cuahsi.org/wofws.html`

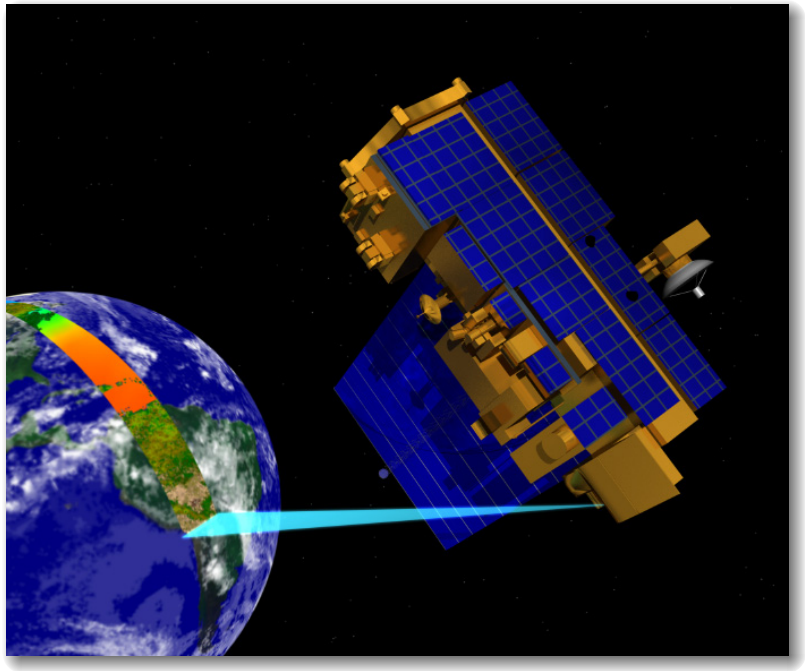
Data Collection using Python

- Suds python package
- Lightweight web services client for python
- Provides an object-like API
- Reads WSDL

```
1  from suds.client import Client
2  url = 'http://river.sdsc.edu/wateroneflow/NWIS/DailyValues.asmx?wsdl'
3
4  # create an instance of the suds Client class
5  client = Client(url)
6
7  # see what functions are available
8  print client
9
10 # call a function
11 client.service.GetValues('NWIS:09429000', 'NWIS:00060',
12 '2000-11-01T00:00:00','2000-12-31T00:00:00','')
```

Practical Example

- Collect MODIS land surface temperature
- Write a python script to collect this data
- Convert the results into Arc rasters and visualize
- Extend to use other tools (time permitting)



Practical Example - Build the base script

```
1  import os                    # standard python package
2  import arcpy                 # arcmap package
3  import modis_base            # package for organizing MODIS data
4  from suds.client import *    # web service client
5
6  # set overwrite to true
7  arcpy.env.overwriteOutput = True
```

```
import numpy

class ModisData():
    def __init__(self, modisdata):
        self.__modisdata = modisdata

        self.__data = {}

        self._set_data()

    def mosisObj(self):
        return self.__modisdata

    def get_cellsize(self):
        return self.__modisdata.cellsize

    def get_bbox(self):
        #xmin ymin xmax ymax]
        return [self.__modisdata.xllcorner,
                self.__modisdata.yllcorner,
                self.__modisdata.xllcorner+self.__modisdata.ncols*self.__modisda
                self.__modisdata.yllcorner+self.__modisdata.nrows*self.__modisda


    def _set_data(self):

        subsets = self.__modisdata.subset
        data = []
        cols = int(self.__modisdata.ncols)

        for row in subsets:
            data = []
            values = row.split(',')
            date = values[2]
            for idx in range(5,len(values),cols):
                start = idx
                end = idx+cols
                data.append([float(val) for val in values[start:end]])

            self.__data[date] = numpy.array(data)

    def get_data(self):
        return self.__data
```

Practical Example - Add Web Services

```
1   import os                    # standard python package
2   import arcpy                 # arcmap package
3   import modis_base            # package for organizing MODIS data
4   from suds.client import *    # web service client
5
6   # setup environment
7   arcpy.env.overwriteOutput = True
8   arcpy.env.workspace = os.getcwd()
9
10  pts = [ (40.115,-110.025),       # add some points to collect data at
11      (40.144341, -109.807629),
12      (39.927865, -109.867392),
13      (40.193480, -110.353466),
14      (40.068641, -110.150605),
15      (40.124420, -109.910932)
16      ]
17
18  output_files = {}                # dictionary to store the results
19  i = 0                            # counter
20  for lat, lon in pts:             # loop over each lat,lon in pts list
21
22      print 'Querying MODIS data...'      # print statements can be helpful
23      wsdl = 'http://daac.ornl.gov/cgi-bin/MODIS/GLBVIZ_1_Glb_subset/MODIS_webservice.wsdl'
24
25      client = Client(wsdl)        # Create instance of suds client
26
27      # call the web service to retrieve data
28      lat, lon = pt
29      result = client.service.getsubset(lat, lon, "MOD11A2","LST_DAY_1km",
30                                        "A2001001","A2001025",10,10)
```

http://daac.ornl.gov/MODIS/MODIS-menu/modis_webservice.html

Practical Example - Add Web Services, pt2

```
33      # ... continued from previous slide
34
35      # organize the results
36      print 'Building Modis Object...'
37      modis_data = modis_base.ModisData(result)
38
39      # get info about the dataset
40      data = modis_data.get_data()
41      modisObj = modis_data.mosisObj()
42      rows = modisObj.nrows
43      cols = modisObj.ncols
44      xmin,ymin,xmax,ymax = modis_data.get_bbox()
45      cellsize = modis_data.get_cellsize()
```

DEMO

Practical Example - Build Rasters, pt1

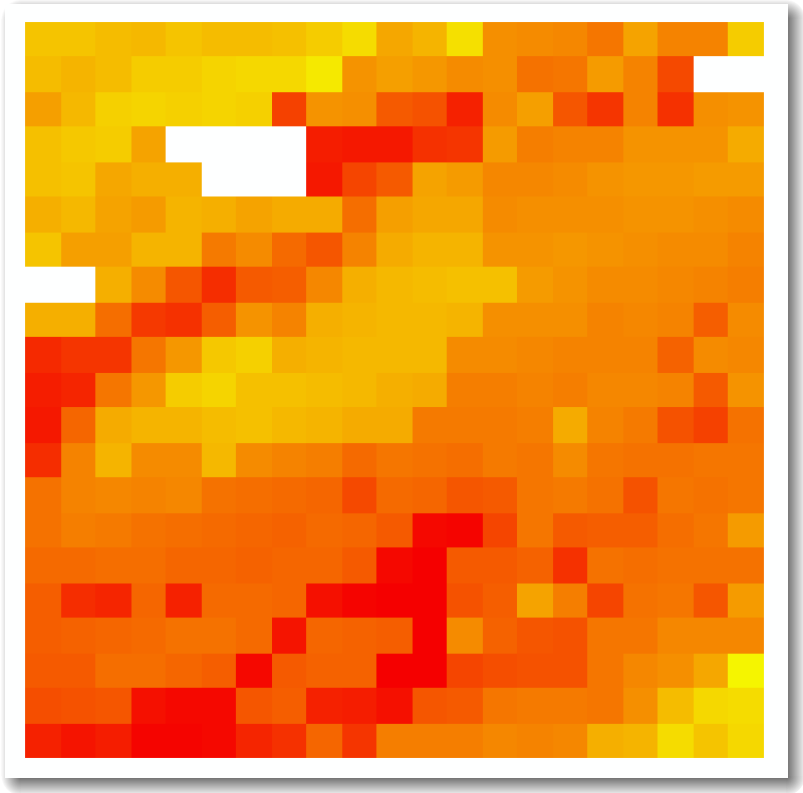
```
33      # create ASCII Raster for all dates retrieved
34      for date in data.keys():
35
36          filename = 'modis_temp_'+date+'.txt'
37          ascii_path = os.getcwd()+'/temp/'+filename
38          with open(ascii_path,'w') as f:
39
40              # write header data
41              f.write('NCOLS %s\n'% cols)
42              f.write('NROWS %s\n'% rows)
43              f.write('XLLCORNER %s\n'% xmin)
44              f.write('YLLCORNER %s\n'% ymin)
45              f.write('CELLSIZE %s\n'% cellsize)
46              f.write('NODATA_VALUE %s\n' % 0)
47
48              d = data[date]
49              for row in d:
50                  for value in row:
51                      if value != 0.0:
52                          value = (value*.02 - 273.15)*1.8 + 32.
53
54                      f.write('%3.2f ' % value )
55                  f.write('\n')
56
57              print 'Process: ASCII to Raster'
58              raster_name = filename.split('_')[-1][:-4]+'_'+str(i)
59              raster = os.path.join(os.getcwd()+'/raster',raster_name)
60              arcpy.ASCIIToRaster_conversion(ascii_path, raster, "FLOAT")
61
62              # continued on next slide ...
```

Practical Example - Build Rasters, pt2

```
63          # ... still inside loop
64
65          print 'Process: Define Projection'
66
67          # Define a custom projection as WKT (MODIS projection)
68          prj = "PROJCS['Sinusoidal', " + \
69                "GEOGCS['GCS_Undefined',DATUM['D_Undefined',SPHEROID['User_Defined_Spheroid',"+\
70                "6371007.181,0.0]],PRIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],"+\
71                "PROJECTION['Sinusoidal'],PARAMETER['False_Easting',0.0],"+\
72                "PARAMETER['False_Northing',0.0],PARAMETER['Central_Meridian',0.0],"+\
73                "UNIT['Meter',1.0]]"
74
75          arcpy.DefineProjection_management(raster, prj)
76
77          # store all output file names in a dictionary based on date
78          if date in output_files:
79              output_files[date].append(raster)
80          else:
81              output_files[date] = [raster]
```

Practical Example - Build Raster Results

```
NCOLS 21.0
NROWS 21.0
XLLCORNER -9355210.41
YLLCORNER 4451508.54
CELLSIZE 926.625433056
NODATA_VALUE 0
48.33 47.82 46.99 46.31 46.13 44.65 44.47 44.47 44.04
47.28 46.71 46.35 45.81 45.77 45.70 45.19 44.58 43.29
45.12 44.73 45.91 45.52 45.59 44.94 44.91 44.44 44.26
43.72 43.61 44.33 46.09 46.35 45.19 44.87 44.83 45.19
44.22 46.24 47.64 47.43 46.09 44.04 44.26 44.26 44.29
48.87 49.05 48.00 46.63 44.47 43.72 43.54 44.73 44.80
0.00 47.17 47.03 46.85 46.67 45.91 0.00 0.00 44.08 45.
48.15 47.14 46.85 46.45 45.34 44.94 0.00 44.08 44.94 4
46.74 47.25 46.99 45.34 45.30 46.45 46.56 46.67 45.59
46.81 47.17 45.73 46.71 46.56 46.20 46.78 46.35 45.88
47.50 47.64 47.79 0.00 0.00 47.57 47.35 43.72 43.86 43
0.00 0.00 0.00 48.54 45.45 43.57 43.90 43.79 43.72 43.
0.00 0.00 0.00 44.37 43.75 43.90 43.79 43.68 43.36 43.
46.13 43.97 44.33 44.62 44.19 44.08 43.83 43.50 43.43
44.91 44.76 44.73 44.47 44.26 43.72 43.25 42.96 43.11
45.05 44.98 44.69 44.22 43.86 43.29 42.82 42.85 43.03
44.76 44.65 44.44 43.86 43.61 43.36 43.21 43.03 42.93
43.86 43.36 43.29 43.29 43.65 43.72 43.68 43.54 43.39
44.29 44.04 44.11 45.19 45.37 45.30 44.37 44.08 43.57
44.62 44.76 44.73 44.91 45.30 45.34 45.01 44.51 44.11
44.58 44.65 45.01 45.19 45.52 45.59 45.41 45.19 44.87
```

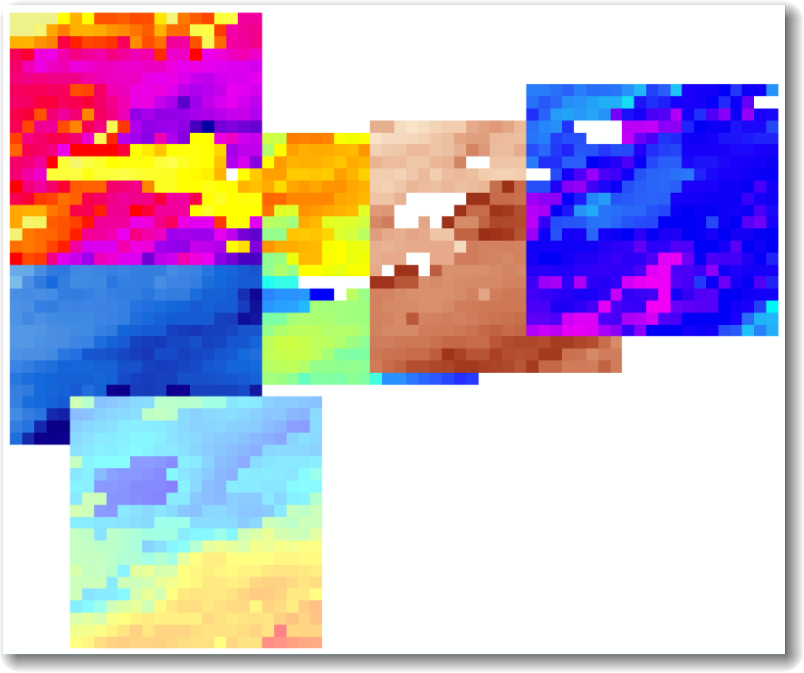


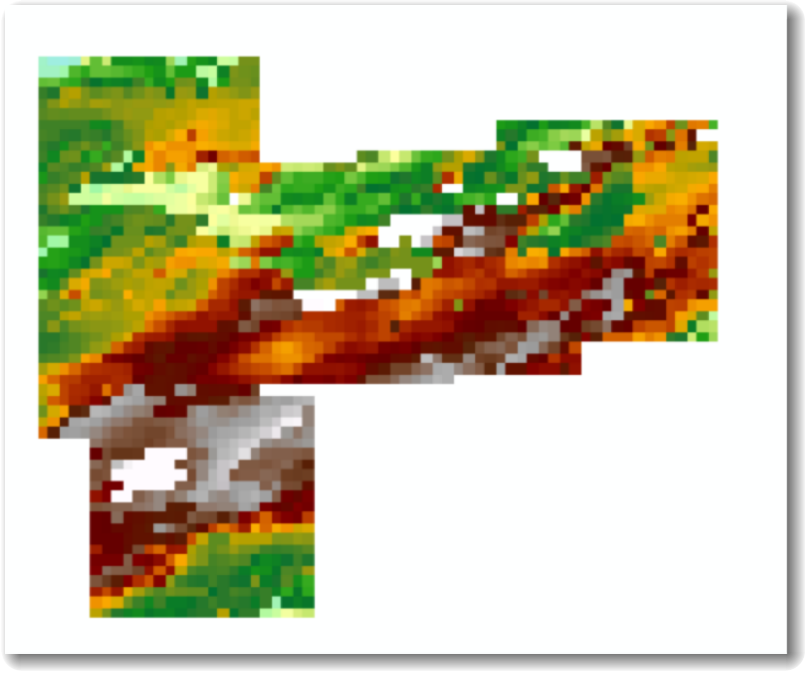
Practical Example - Add Mosaic Tool

```
83    print 'Process: Mosaic'
84    for key in output_files.keys():
85
86        # build a new mosaic dataset
87        file_list = output_files[key]
88        files = ';'.join(file_list)
89        arcpy.MosaicToNewRaster_management( files, '/mosaic', key, prj,
90                                            "8_BIT_UNSIGNED", "40", "1",
91                                            "LAST","FIRST")
```

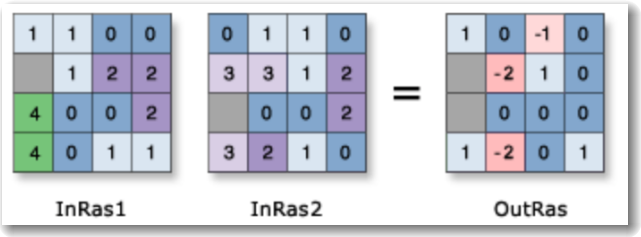
```
==================================
Mosaic
Usage: Mosaic_management inputs;inputs... target
       {LAST | FIRST | BLEND | MEAN | MINIMUM | MAXIMUM} {FIRST | REJECT | LAST | MATCH}
       {background_value} {nodata_value} {NONE | OneBitTo8Bit} {mosaicking_tolerance}
                          {NONE | STATISTIC_MATCHING | HISTOGRAM_MATCHING
                          | LINEARCORRELATION_MATCHING}
```

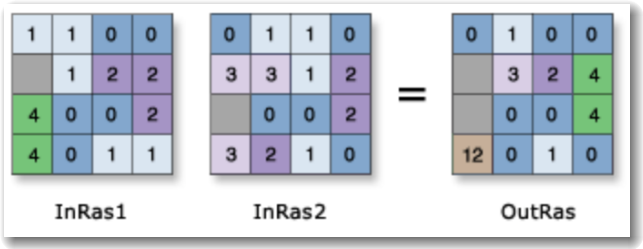
Mosaic Results





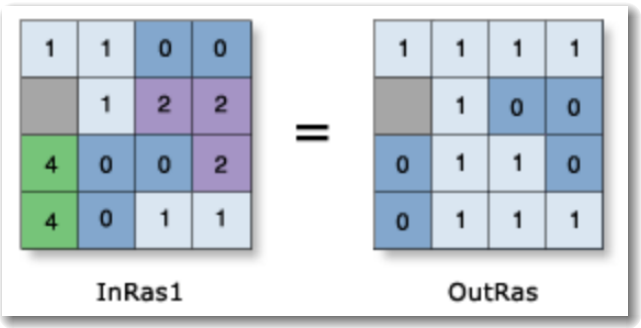
How about some Geoprocessing

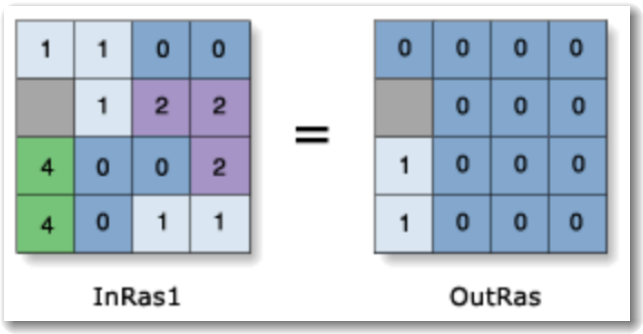




- Determine locations where surface temperature increased
- Determine locations where surface temperature decreased

```
1  # Check out the ArcGIS extension license
2  arcpy.CheckOutExtension("Spatial")
3  from arcpy.sa import *
4
5  # calculate locations where surface temperature increased
6  r1 = '/mosaic/'+output_files.keys()[0]
7  r2 = '/mosaic/'+output_files.keys()[-1]
```



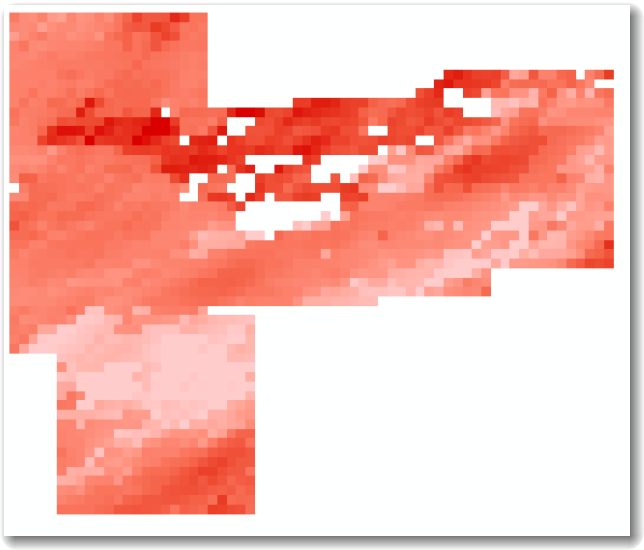


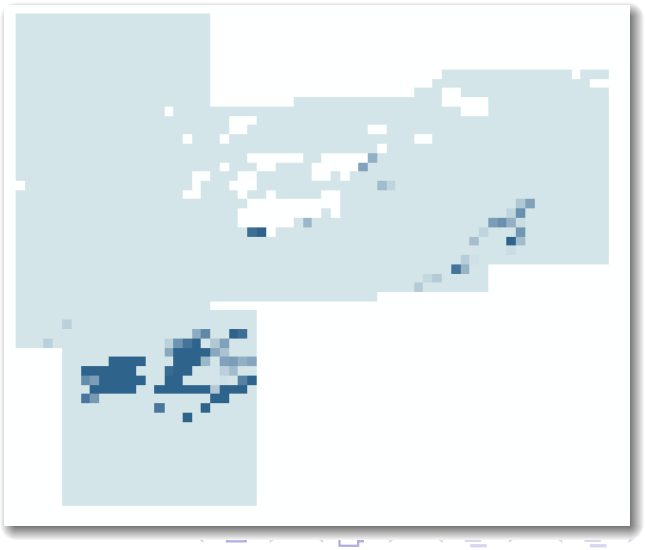
Calculating Temperature Increase

```
 9    # ... continued from previous slide
10
11    # Execute Minus
12    print 'Executing Minus...'
13    diff = os.getcwd()+'/temperature/diff'
14    outMinus = Minus(r2, r1)
15    outMinus.save(diff)
16
17    # Execute GreaterThan: find all cells greater than 0
18    print 'Execute GreaterThan...'
19    gt = os.getcwd()+'/temperature/gt'
20    outGreaterThan = GreaterThan(diff, 0)
21    outGreaterThan.save(gt)
22
23    # Execute Times isolate all cells where temperature increased
24    print 'Execute Times...'
25    inc = os.getcwd()+'/temperature/increased'
26    outTimes = Times(diff, gt)
27    outTimes.save(inc)
```

Calculating Temperature Decrease

```
27  # ... continued from previous slide
28
29  # Execute LessThan: find all cells less than 0
30  print 'Execute LessThan'
31  lt = os.getcwd()+'/temperature/lt'
32  outLessThan = LessThan(diff, 0)
33  outLessThan.save(lt)
34
35  # Execute Times isolate all cells where temperature increased
36  print 'Execute Times...'
37  dec = os.getcwd()+'/temperature/decreased'
38  outTimes = Times(diff, lt)
39  outTimes.save(dec)
```





Interactive Debugging

DEBUGGING DEMO (time permitting)

Summary of Concepts

- ArcGIS can be extended to implement new functionality using Python
- Python can also be used to automate repetitive tasks
- Tools can leverage web services to download data
- Python (and .Net) bindings have been developed for most of the ArcToolBox
- Documentation for every tool is provided on the ArcGIS website