Cultivating an Emergent Earth Observation Analytics Ecosystem in the Cloud

Christopher Lynnes*, NASA/Goddard Space Flight Center

System Architect
Earth Observing System Data and Information System

*U.S. Civil Servant
We are in a golden age of Earth Observations

- Dozens of Earth Observation Satellites
- Many agencies with Open Data policies
- Tens of thousands of datasets
Data analysis tools and services abound
How Do We Make Full Use of Everything?

- Dependency on research problem
- Evolution of key components
  - instruments
  - analysis methods
- Tool and service providers in different
  - Countries
  - Agencies
  - Companies
Answer:

It’s Complicated...
Answer:

...or is it Complex?
Complex Adaptive Systems (CAS)

1. Multiple components
2. Varying degrees of heterogeneity
3. Inter-component interactions: signals and rules
4. No central authority
5. Emergent behavior: whole > sum of parts
## Complicated vs. Complex Adaptive Systems

<table>
<thead>
<tr>
<th>Complicated System</th>
<th>Complex Adaptive System</th>
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<tbody>
<tr>
<td>Loss of one individual component -&gt; system impairment</td>
<td>Loss of one individual -&gt; system adaptation (usually)</td>
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<tr>
<td>Completely deterministic</td>
<td>Unexpected behavior arising from ensemble interactions</td>
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<tr>
<td>Example: internal combustion engine</td>
<td>Examples: ecosystems, economies, ant colonies, genetic algorithms...</td>
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Earth Observation Analytics as CAS

- Multiple components: datasets, analysis software
- Varying degrees of heterogeneity
- Inter-component interactions:
  - Application Program Interfaces
  - Services
- No central authority
- Emergent behavior?
Can Complexity Theory Help?

1. Derive lessons from “similar” Complex Adaptive Systems
   a. The Internet
   b. The World Wide Web

2. Analogies from work in Complex Adaptive Systems
   a. Bucket Brigade
   b. Recombination
The Internet

Killer App

Email

Application Support Standards

SMTP | POP | IMAP

Simple Foundational Standards

TCP/IP

SMTP: Simple Mail Transfer Protocol (1982)
The World Wide Web

Killer App

Web Browser
Web Server

Application Support Standard

HTML

Simple Foundational Standard

HTTP

HTML: Hypertext Markup Language (1991)
Earth Observation Analytics

Killer App

Application Support Standards

Simple Foundational Standards

WCPS? WPS?

OPeNDAP? OpenAPI?

WCPS: Web Coverage Processing Service
WPS: Web Processing Service
OPeNDAP: Open-source Project for a Network Data Access Protocol
OpenAPI: Open Application Program Interface
Analogies from Complex Adaptive Systems
"Bucket Brigade" Credit Assignment to brokers

New role for provenance?
Adaptation by Recombination (Genetic Algorithms)

*Combine syntactic and semantic standards?*

<table>
<thead>
<tr>
<th>Syntactic</th>
<th>Semantic</th>
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<tr>
<td>OpenSearch</td>
<td>schema.org</td>
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<tr>
<td>OpenAPI</td>
<td>DCAT</td>
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<tr>
<td>WCS</td>
<td>SWEET</td>
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<td>ISO 19115</td>
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- OpenAPI: Open Application Program Interface
- WCS: Web Coverage Service
- DCAT: Data Catalog Vocabulary
- SWEET: Semantic Web for Earth and Environmental Terminology
Going Forward...

1. Embrace Earth Observation Analytics as a Complex Adaptive System
2. Leverage combinations of simple protocols and standards
3. Ensure proper credit to participating agents
4. (Keep an eye out for dysfunctional emergence)
Acronym List

API  Application Program Interface
caret  Classification and regression training
CAS  Complex Adaptive System
DCAT  Data Catalog Vocabulary
GDAL  Geospatial Data Abstraction Library
GIS  Geographic Information System
GMT  Generic Mapping Tools
GRASS  Geographic Resources Analysis Support System
HTML  Hypertext Markup Language
HTTP  Hypertext Transfer Protocol
IDL  Interactive Data Language
IDV  Integrated Data Viewer
IMAP  Internet Message Access Protocol
IP  Internet Protocol
ncdf  netCDF
nco  netCDF Command Operators
netCDF  network Common Data Form
OPeNDAP  Open-source Project for a Network Data Access Protocol
pandas  Python Data Analysis Library
POP  Post Office Protocol
SeaDAS  SeaWiFS Data Analysis System
SeaWiFS  Sea-viewing Wide Field-of-View Sensor
SMTP  Simple Mail Transfer Protocol
SNAP  Sentinel Application Platform
SWEET  Semantic Web for Earth and Environmental Terminology
TCP  Transmission Control Protocol
WCPS  Web Coverage Processing Service
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