



Cultivating an Emergent Earth Observation Analytics Ecosystem in the Cloud

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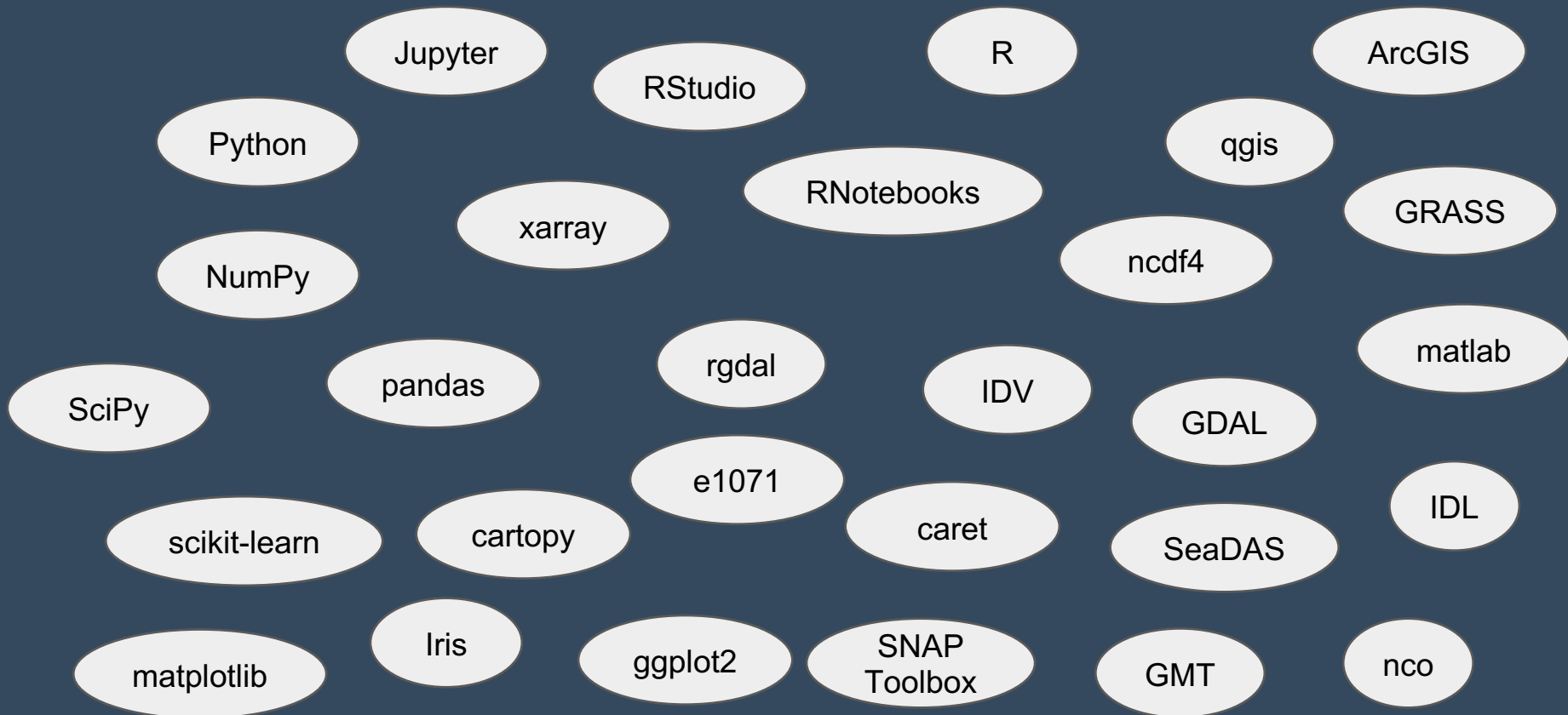


We are in a golden age of Earth Observations

- 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...



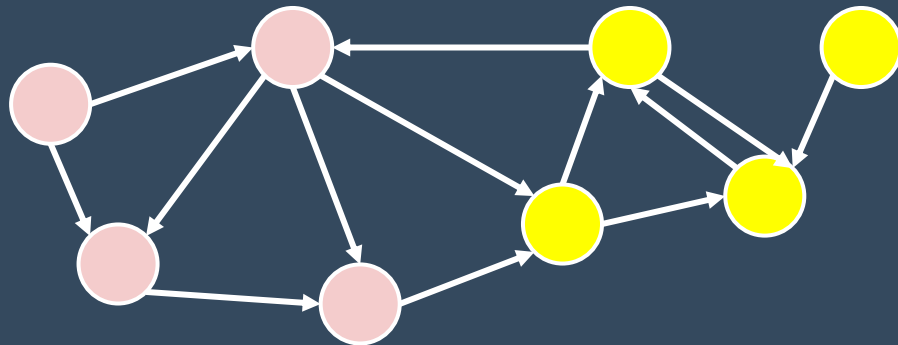
Answer:

...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: $\text{whole} > \text{sum of parts}$





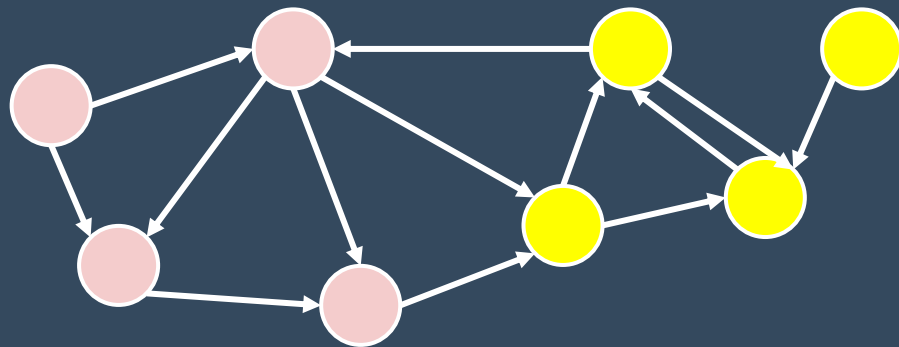
Complicated vs. Complex Adaptive Systems

Complicated System	Complex Adaptive System
Loss of one individual component -> system impairment	Loss of one individual -> system adaptation (usually)
Completely deterministic	Unexpected behavior arising from ensemble interactions
Example: internal combustion engine	Examples: ecosystems, economies, ant colonies, genetic algorithms...



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)

POP: Post Office Protocol (1984)

IMAP: Internet Message Access Protocol (1986)

TCP: Transmission Control Protocol (1974)

IP: Internet Protocol (1980)



The World Wide Web

Killer App

Web Browser
Web Server

Application Support Standard

HTML

Simple Foundational Standard

HTTP

HTML: Hypertext Markup Language (1991)
HTTP: Hypertext Transfer Protocol (1991)



Earth Observation Analytics

Killer App

Machine Learning?

Application Support Standards

WCPS? WPS?

Simple Foundational Standards

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

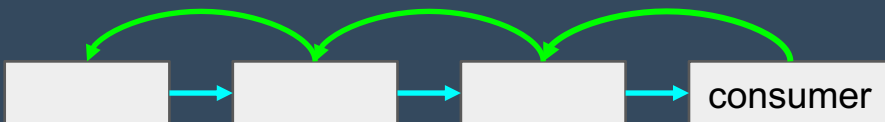


Analogies from Complex Adaptive Systems

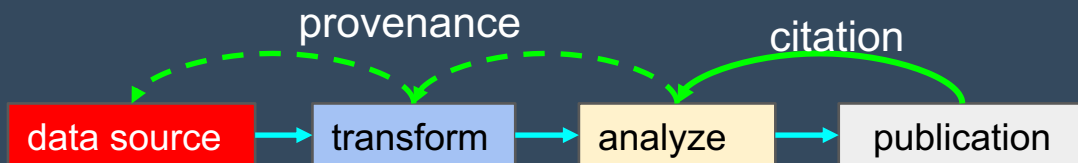


Bucket Brigade Algorithm and Provenance

“Bucket Brigade” Credit Assignment to brokers



New role for provenance?





Adaptation by Recombination (Genetic Algorithms)

Combine syntactic and semantic standards?

Syntactic
OpenSearch
OpenAPI
WCS

Semantic
schema.org
DCAT
SWEET
ISO 19115

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