Big Data for Big Problems

34th International Conference on Massive Storage Systems and Technology (MSST 2018)
Monday, May 14, 2018, 2-6 p.m.
Santa Clara University

A tutorial presented by:
- Norman R. Kraft (Georgetown)
- Helen Karn (Georgetown)
- Stephen Baird (AdaCore)
## AvesTerra Tutorial Schedule

<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
</tr>
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<tbody>
<tr>
<td>2:00 to 2:30 p.m.</td>
<td>Ada 2012, Spark, and AdaCore</td>
</tr>
<tr>
<td>2:30 to 3:45 p.m.</td>
<td><strong>AvesTerra architecture</strong></td>
</tr>
<tr>
<td>3:45 to 4:15 p.m.</td>
<td>Break</td>
</tr>
<tr>
<td>4:15 to 5:30 p.m.</td>
<td>AvesTerra adapters</td>
</tr>
<tr>
<td></td>
<td>AvesTerra toolkit and API</td>
</tr>
<tr>
<td>5:30 to 6:00 p.m.</td>
<td>AvesTerra roadmap</td>
</tr>
<tr>
<td></td>
<td>Questions and Discussion</td>
</tr>
</tbody>
</table>
The AvesTerra Team

Georgetown University

• J. C. Smart, AvesTerra Chief Scientist
• David Bridgeland, AvesTerra adapters, toolkit, API
• Norman Kraft, AvesTerra adapters, toolkit, API
• Helen Karn, AvesTerra ontology and taxonomies
• John Cederholm, AvesTerra Visualization Utility (AVU)
• Jianan Su, AvesTerra testing

Collaborating institutions

• American University
• Lawrence Livermore National Laboratory (LLNL)
• LEDR Technologies Inc.
• Oak Ridge National Laboratory (ORNL)
• Pacific Northwest National Laboratory (PNNL)
AvesTerra architecture

Van Gogh from Space, USGS/NASA/Landsat 7, July 13, 2005
**AvesTerra's Big Data focus**

1. Extreme scale  
2. Highly distributed  
3. Highly complex organizations  
4. Multi-disciplinary use cases  
5. Unique organizational cultures  
6. Differing privacy policies  
7. Data sharing but not sharing data

*It’s not necessarily* the amount of data... but where it is and how it’s shared
Why is “connecting-the-dots” so hard?

- **Plumbing**: Massive logistics problem to integrate thousands of government/non-government data systems at scale
  - Different standards, models, security, infrastructure, procedures, policies, networks, access, compartments, applications, tools, protocols, etc. … all at immense scale!

- **Protection**: Large-scale integration of data resources increases cyber security risks
  - Prevention of adversary exploitation of strategic national assets.

- **Patterns**: Lack of analytic algorithm techniques to automatically detect data patterns and alert
  - Transition from “analytic dumpster diving” to early-warning indication and real-time notification

- **Privacy**: Significant tension between security and liberty
  - Who trusts the “watchers”?
  - Who watches the watchers?

- **Politics**: What’s in it for me?
Use case: U.S. intelligence community

17 different organizations with different missions

Sharing without sharing
Solution: A large graph

- AvesTerra manifests the appearance of a big graph
- The graph is a knowledge hypergraph
Ultragraph example

\[ R \subseteq E \times E \]

\[ R \subseteq \mathcal{P}(\mathcal{P}(\ldots \mathcal{P}(E))) \]
Ubergraph example

“Dad” → Spouse → “Mom”

“Alice” → Parents → “Bob”

“My Family” (1234, “Main St”)

D= 411  I= 42  K= 20  DD= 82.2  ID= 8.4  KD= 0.8000  J= 25.0
Ubergaph example (cont)

"Mom"
"Dad"
"Bob"
"Alice"

Spouse
Spouse
Children
Parents
Parents
Children
Siblings
Siblings

"My Family"
(1234, "Main St")

"Cleaver Family"
(485, "Mapleton Dr.")

D = 814  I = 84  K = 40  DD = 81.4  ID = 8.4  KD = 0.4000  J = 50.0
Ubergraph example (cont)
AvesTerra Graph Families

- Ubergraphs
- Ultragraphs
- Hypergraphs
- Graphs
- Factor Graphs
- Trees
The nodes of the big graph = entities

An entity is any THING that can be observed, measured, or described:

- MSST 2018, MSST 2017
- Adacore, Apple, Facebook, Google, Qualcomm
- Santa Clara, Silicon Valley, Washington, DC, California, U.S.A., Basque Country, Spain
- Santa Clara University, Georgetown University
- Norm Kraft, Helen Karn, Steve Baird
- the Society of Jesus ("the Jesuits")
- Association of Jesuit Colleges & Universities
Every entity belongs to a class

PERSON_CLASS
Steve Baird, Norm Kraft, Helen Karn, Ignatius of Loyola

ORGANIZATION_CLASS
AdaCore, Georgetown University, Santa Clara University
Society of Jesus ("the Jesuits"), Association of Jesuit Colleges & Universities (AJCU)

LOCATION_CLASS
Santa Clara, District of Columbia, Pamplona, California, Basque Country, United States of America, Spain
Classes and subclasses form a taxonomy

ORGANIZATION_CLASS

BUSINESS_SUBCLASS
   Adacore

COLLEGE_SUBCLASS
   Santa Clara University
   Georgetown University

COMMUNITY_SUBCLASS
   Society of Jesus [the Jesuits]

ORGANIZATION_SUBCLASS
   Association of Jesuit Colleges & Universities (AJCU)
Entities have attributes

PERSON_CLASS

Entity: Ignatius of Loyola

Attributes:

SEX_ATTRIBUTE: Male
LANGUAGE_ATTRIBUTE: Basque
NAME_ATTRIBUTE: Iñigo, Igacio, Ignatius
FAMILY_ATTRIBUTE: López de Loyola y Onaz
HEALTH_ATTRIBUTE: Poor
RELIGION_ATTRIBUTE: Roman Catholic
### An attribute value can be another entity

<table>
<thead>
<tr>
<th>Entity:</th>
<th>Ignatius of Loyola</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attributes:</td>
<td>OCCUPATION ATTRIBUTE: page, soldier, priest, saint</td>
</tr>
<tr>
<td></td>
<td>LOCATION ATTRIBUTE: Azpeitia, Pamplona, Montserrat, Manresa, Rome</td>
</tr>
<tr>
<td></td>
<td>ASSOCIATION ATTRIBUTE: Society of Jesus</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Entity:</th>
<th>Society of Jesus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attributes:</td>
<td>NAME ATTRIBUTE: Compañía de Jesús, the Jesuits</td>
</tr>
<tr>
<td></td>
<td>MANAGER ATTRIBUTE: Saint Ignatius of Loyola, [+29 more], Arturo Sosa</td>
</tr>
<tr>
<td></td>
<td>ASSOCIATION ATTRIBUTE: Georgetown University, Santa Clara University, Loyola University Chicago [+90 more]</td>
</tr>
<tr>
<td></td>
<td>PURPOSE ATTRIBUTE: education, retreats</td>
</tr>
</tbody>
</table>
Attribute values cross server boundaries
Entities can have properties

Entity: Ignatius of Loyola

Properties:
- hobbies: riding, dueling, gambling, billiards, dancing, womanizing
- injured-year: 1521
- injured-by: cannonball
- injured-place: Pamplona
- friends-of: Francis Xavier, Peter Faber
- canonized-date: March 12, 1622
**AvesTerra properties vs. attributes**

<table>
<thead>
<tr>
<th>Properties</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Situation-specific</td>
<td>Universal semantics</td>
</tr>
<tr>
<td>Unlimited number</td>
<td>Limited number</td>
</tr>
<tr>
<td>User-defined strings</td>
<td>AvesTerra ecosystem-defined</td>
</tr>
</tbody>
</table>
**Knowledge Overlay** is a technique used to create a shared semantic representation of a complex system that spans *many* diverse contributing organizations, data sources, and analytic components.

**AvesTerra Design Criteria:**

- Global-scale (trillions of entities/quadrillions of relationships)
- Collaborative/Distributed (thousands/millions of participants)
- Semantic expressivity (complex physical and virtual systems)
- Multi-domain (hundreds/thousands)
- Multi-modal (hundreds/thousands)
- Multi-fidelity (microscopic to macroscopic)
- Dynamic (real-time, changing information flows)
- Analytic/semantic interoperability
- Minimized data movement/replication
AvesTerra:
An overlay on existing data sources
AvesTerra Adapters

The AvesTerra global knowledge network is an ambitious project to connect the world's knowledge.

However the conceptual graph by itself isn't useful.
AvesTerra Layered Architecture

AvesTerra Applications
(Adapters, Analytics, Visualizers)

AvesTerra Services
(Ontology management, query support, analytic libraries, reasoning, hypothesis management, etc.)

AvesTerra Toolkit
(Collaborative Knowledge Representation)

AvesTerra API
(Peer-to-Peer Knowledge Overlay)

HGTP

Internet
AvesTerra Entity Logical Addressing

UUID = <PID|HID|UID>
PID: 32 bits
HID: 32 bits
UID: 64 bit
AvesTerra Distributed Remote Rendezvous

Entity E

Server_E

HGTP.Invoke(E,...)

Server_C

HGTP.Invoke(E,...)

Server_A

HGTP.Invoke(E,...)

Outlet O

Server_O

HGTP.Adapt(O,...)

HGTP.Invoke(E,...)

HGTP.Adapt(O,...)

HGTP.Adapt(O,...)

HGTP.Adapt(O,...)

WAN/LAN

(Internet)

Client C

API.Create(E)

API.Connect(E,O)

API.Invoke(E,...)

API.Invoke(E,...)

API.Invoke(E,...)

Adapter A

API.Create(O)

API.Activate(O)

API.Adapt(O,...)

loop

API.Adapt(O,...)

end loop

Georgetown Proprietary
AvesTerra Common Model

Entity

Attribute$_1$

Attribute$_n$

Properties

Values

Properties

Values
AvesTerra Common Model (Enhanced)
AvesTerra Layered Architecture

Analytic Ecosystem

Analytic Language

Analytic Suite

Analytic Builder

Analytic Toolkit

Analytic Algebra

AvesTerra API

AvesTerra (V2.0)  AvesTerra – Reference (V3.0+)

Cassandra  Web Services  HGTP

Internet
AvesTerra API

Summary

Primitives:
• CREATE/DELETE (entities)
• CONNECT/DISCONNECT (methods)
• ATTACH/DETACH (attributes)
• INVOKE/INQUIRE (method/attribute access)
• REFERENCE/DEREFERENCE (garbage collection)
• ACTIVATE/DEACTIVATE (rendevous/queues)
• ADAPT/RESET (Adapters)
• PUBLISH/SUBSCRIBE/CANCEL (Events)
• WAIT/CLEAR (Subscribers)
• CALL/NOTIFY (RPC & subscriber notification)
• AUTHORIZE/DEAUTHORIZE (access control)
• REPORT (auxiliary functions)

Current Bindings: Python, Swift, Ada, Java, C++
In Progress: Clojure, R
Available: avesterra@georgetown.edu
What is an Adapter?

The AvesTerra graph needs information, and most of that will come from traditional data sources.

Adapters connect and translate data sources like databases and spreadsheets for the AvesTerra network and nodes communicate with each other via the HGTP protocol.

Adapters can also apply analytics to entities, on demand.

Adapters are gateways between your data and the knowledge network.
There Are Three Kinds of Adapters

1. Read-only adapters (Web, Secured Data, REST, etc)

2. Read-Write adapters
   • Difference between knowledge network enrichment and updating a data store

3. Information adapters
Adapter Methods

Eight Basic Operations on Entities:

- CREATE
- DELETE
- INVOKE
- INQUIRE
- REFERENCE
- DEREference
- SEARCH
- INDEX

Two Bulk Entity Operations:

- STORE
- RETRIEVE
Things an Adapter Must Do

• Receive AvesTerra entities with methods and attributes

• Translate the request into a local datastore query

• Apply analytics, if needed or requested

• Convert the query response into an AvesTerra entity

• If an entity is created, keep track of entity ID and local data ID

• Optional but recommended: cache frequent requests
Adapters are Customized to Your Data Source

While you may have a large PostgreSQL database, the adapter would present data in your tables as AvesTerra entity attributes and properties.

In the construction of the adapter, an organization has an opportunity to limit what data is shared.
AvesTerra Toolkit and API

Since AvesTerra uses a custom protocol (HGTP) for communication, an API has been defined for the protocol.

From this API, low level bindings have been developed in several programming languages for the purpose of adapter and application development.

Because the low level bindings are not fun to use, we have also created the AvesTerra toolkits for each language binding. These toolkits simplify development.
What is the HGTP Communications Protocol?

HGTP is a simple all-text protocol with positional content. The communications protocol is based on a ACK/NAK system.

The simplicity of the HGTP protocol has two goals:

• To make application and binding development available across a wide variety of programming languages.

• A simple protocol allows for enhanced security, as scanning the positional data in a message does not require a complex parser.
Message Packets Contain Entities
An Entity

Entity:  <2906857743|167772516|471952>
Name:    "winona"
Class:  PERSON_CLASS
Subclass: NULL_SUBCLASS
Server:  <2906857743|167772516|0>
Timestamp:  2018-01-30 19:04:27
Activated:  FALSE
References:  0
Attachments:  0
Connections:  1
<0|0|11> NULL_METHOD 1
Subscriptions:  0
Authorizations:  0
Attributes:
  HEIGHT_ATTRIBUTE  1.61
  LOCATION_ATTRIBUTE  <2906857743|167772516|471953>
  AGE_ATTRIBUTE  46
Properties:
  acting credits  []
  acting credits  []
  acting credits  []
  acting credits  []
  producing credits  []
  acting credits  []
Edward Scissorhands
The Age of Innocence
A Scanner Darkly
Stranger Things
Girl, Interrupted
Girl, Interrupted
The Avesterra Toolkits

The AvesTerra bindings are available in several languages.

The AvesTerra Toolkits have been created to make working with those bindings easier and at a higher level.

What would have taken five or six method calls at the binding level is often only one or two method calls in the toolkit.

Toolkit-based code is shorter, more functional and easier to comprehend.
## AvesTerra Roadmap (2017-2018)

<table>
<thead>
<tr>
<th>Version</th>
<th>Release Date</th>
<th>Features</th>
</tr>
</thead>
</table>
| 3.0     | October 2017     | - AvesTerra API  
- AvesTerra Toolkit  
- AvesTerra Visualization Utility (AVU) |
| 3.1     | January 2018     | - Weather adapter  
- Enhancements to API exception handling  
- API bindings refresh  
- Enhancements to AVU (interim) |
| 3.2     | April 2018       | - Climate adapter  
- GMS adapter (Phase I)  
- EOS adapter (Phase I)  
- Ontology manager (Phase I)  
- Uncertainty Model (Design)  
- Provenance Model (Design)  
- Python callbacks binding  
- Enhancements to exception reporting  
- Enhancements to AVU (Phase I) |
### AvesTerra Roadmap (2018-2020)

<table>
<thead>
<tr>
<th>Version</th>
<th>Release Date</th>
<th>Features</th>
</tr>
</thead>
</table>
| 3.3     | July 2018    | • GMS adapter (Phase II)  
|         |              | • EOS adapter (Phase II)  
|         |              | • Ontology manager (Phase II)  
|         |              | • Uncertainty Model (Implementation)  
|         |              | • Provenance Model (Implementation)  
|         |              | • Enhancements to AVU (Phase II)  |
| 3.4     | October 2018 | • GMS adapter (Phase III)  
|         |              | • Ontology manager (Phase III)  
|         |              | • Enhancements to AVU (Phase III)  |
| 4.0     | 2019         | • Server protocol plug-ins  
|         |              | • Server routing plug-ins  
|         |              | • Containerization  |
| 5.0     | 2020         | • AvesTerra Analytic Language  
|         |              | • AvesTerra Analytic Environment  
|         |              | • ATra integration  |
Questions and Discussion

• **Norman Kraft**, Senior Software Engineer, Georgetown University
  ([Norman.Kraft@georgetown.edu](mailto:Norman.Kraft@georgetown.edu))

• **Helen Karn**, Research Specialist – Computational Sciences, Georgetown University ([karnh@georgetown.edu](mailto:karnh@georgetown.edu))

• **Steve Baird**, Senior Software Engineer, AdaCore ([baird@adacore.com](mailto:baird@adacore.com))
AvesTerra Resources

Web: https://avesterra.georgetown.edu/
Email: avesterra_admin@georgetown.edu
Sponsor: Office of the Senior Vice President for Research, https://osvpr.georgetown.edu

Browse the AvesTerra web site for:

- The Four-Color Framework (April 2016)
- Theoretical Framework (May 2017)
- AvesTerra Application Programming Interface (API) (v. 3.2, May 2018)
- AvesTerra Toolkit (as of March 2018)
- AvesTerra JSON Schemas (as of February 13, 2018)
- Hypergraph Transfer Protocol (HGTP) (v. 1.4, May 2018)
- AvesTerra Taxonomies and Ontology (as of May 2018)
- AvesTerra Roadmap (last updated December 8, 2017)
Acknowledgements

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"Towards an Infectious Disease Insight Center: Privacy and Efficacy Pilot Study". Supplement to NIH Award 5U01A1034994. "Privacy Data Sharing Tool to Support De-duplication of Cases in the National HIV Surveillance System (NHSS)", CDC Contract 211-2016-M-92074. "De-duplication of Case Pairs in the National HIV Surveillance System Using the Black Box", CDC Project Grant NU62PS924580-01-00.
Additional references
