Agent Framework For Intelligent Data Processing

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Data Processing and Mining

• Terminology:
  – data processing = data preparation

• Observations:
  – Majority (80%) of the scientist’s time is spent preparing the data
  – Remainder (20%) of the time is used for actual analysis and mining
  – There are few data preparation/processing steps are commonly used on many different kinds of data especially imagery data
    • Subsetting, Data Format Translation, Subsampling
Can we automate Science Data Processing?

- Yes, but the current methodology involves using:
  - scripts with explicit domain knowledge
  - local data, services
- Adapt to the changing computational environment
  - Web services
    - Semantic Web
  - Grid Services
    - Semantic Grid
- User specifies a goal instead of steps with detailed information required to achieve the goal
  - The different services with proper details are chained together to execute the users task
  - Example:
    - *Subset temperature fields over Florida from TMI dataset for Summer 2002*
Challenges

• **Specifying a query (Natural Language Processing Research)**

• **Optimal service composition (Planning Research)**

✔ **Metadata**
  
  Services require a rich set of metadata
  
  • **Structural metadata**: to provide full description of the data file in bits & bytes, to allow application to read the data
  
  • **Semantic metadata**: to provide meaning of the data along with a context, to allow application to understand what it has read and how to use it

✔ **Data Processing Framework**
Project Objectives

- Design a Metadata Solution
  - Use Earth Science Markup Language (ESML) for structural metadata description
  - Enhance ESML description by providing semantic metadata by leveraging ontologies
- To design and implement a proof of concept Agent Framework (MIDAS) to:
  - leverage the semantic metadata and ontologies for reasoning
  - provide an intelligent, automated processing capabilities for Science data
  - be scalable and adaptable
  - integrate and exploit distributed standalone applications, web services and grid services
Metadata Solution: Background

- Earth Science Data Characteristics
  - Different formats, types and structures (18 and counting for Atmospheric Science alone!)
  - Some formats lack metadata whereas others are metadata rich ($)

- Heterogeneity leads to Data usability problem
Metadata Solution: Background

Data Usability Problem
- Requires specialized code for every format
  - Difficult to assimilate new data types
  - Makes applications tightly coupled to data
- One possible solution - enforce a Standard Data Format
  - Not practical for legacy datasets
Metadata Solution:
Earth Science Markup Language (ESML)

- ESML (external metadata) files containing the structural description of the data format
- Applications utilize these descriptions to figure out how to read the data files resulting in data interoperability for applications
Metadata Solution: Vertical Metadata Integration via Ontologies

- Horizontal Metadata Integration
  - Mediation services
  - Yellow page services
- Vertical Metadata Integration focuses on semantics for the use of the data by an application
- Both Structural and Semantic metadata are required
Metadata Solution: Extending ESML with Ontologies

- ESML Schema provides structural metadata
- Extend ESML schema by embedding semantic terms in the ESML Description File to provide a complete description of the data
- Allow various science communities can create their own ontologies (for example, SWEET) and use them with ESML Description Files for their data
**Metadata Solution:**

**Example of Embedding Semantics in ESML**

```xml
<a:ESML xmlns:a="ESML" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="ESML.xsd">
  <SyntacticMetaData>
    <Binary>
      <Structure instances="1" name="SampleSet">
        <Array occurs="100">
          <Field name="UWind" type="Int32" order="LittleEndian"/>
        </Array>
        <Array occurs="100">
          <Field name="DimX" type="Int32" order="LittleEndian"/>
        </Array>
        <Array occurs="100">
          <Field name="DimY" type="Int32" order="LittleEndian"/>
        </Array>
      </Structure>
    </Binary>
  </SyntacticMetaData>
</a:ESML>
```

ESML Description File embedded with Semantic Tags defined in separate ontologies

```xml
<a:ESML xmlns:a="ESML" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="ESML"
xsi:extension="http://www.daml.org/2001/03/daml+oil#"
xmllns:itsc="http://www.itsc.uah.edu/esml-ex#">
  <SemanticMetaData>
    <Latitude rdf:ID="DimX"/>
    <Longitude rdf:ID="DimY"/>
    <DataField rdf:ID="UWind"/>
    <DataSet rdf:ID="SampleSet">
      <hasField rdf:resource="#DimX"/>
      <hasField rdf:resource="#DimY"/>
      <hasField rdf:resource="#UWind"/>
    </DataSet>
  </SemanticMetaData>
  <SyntacticMetaData>
    <Binary>
      <Structure instances="1" name="SampleSet">
        ..................                       
        </Structure>
      </Binary>
    </SyntacticMetaData>
</a:ESML>
```

Original ESML Description File containing only structural metadata

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Image Information Mining, IGARSS 2004, Anchorage, AK
MIDAS Agent Framework Design: Layer Architecture

- **Infrastructure Layer**: provides the environment that agents can act upon, i.e. services
- **Agent Layer**: contains the agents used to achieve the overall goal of the framework
- **Organization Layer**: defines the organizational structure of the system which is important for agents interaction
- **Coordination Layer**: defines coordination methods required to resolve conflicts and select the next agent
- **Constraint Layer**: verifies whether the system goals are met and interfaces with the users/user interface
MIDAS Agent Framework Design: Infrastructure Layer

- Consists of services domain
  - Search
  - Subsetting
  - Data Format Translation
  - Calibration
  - Navigation
  - Reprojection
  - Visualization
  - Aggregation
  - Fusion
  - Mining
MIDAS Agent Framework Design: Agent Characteristics and Types

• All the agents have the following characteristics:
  – Role
  – Behavior - methods/functions that it can act upon
  – State – store information of itself and the world it perceives
  – Intelligence/Knowledge– to be able to make decisions via ontologies and a reasoning engine or via a machine learning algorithm or via heuristic algorithm
  – Communication protocol – to interact with other agents

• Types of Agents in the Layer
  – Manager Agents
    • Global Manager
    • Domain Manager
  – Worker Agents
MIDAS Agent Framework Design: Agent Description

- **Global Manager Agent**: Given an user input request, distribute the work and collate results
- **Domain Manager Agent**:
  - Keeps a registry of all the Worker agents in its domain
  - All Worker agents advertise their capabilities to the Manager Agent
  - Parses the incoming message and uses an ontology to find the “correct” Worker agent
  - Polls Worker agents for results
  - Fires and Hires Agents
- **Worker Agent**: Uses ESML semantic metadata and ontologies to map input message to API requirements of the Service
  - Example:
    - Navigate the data
    - Map Parameter Concept to Field Name(s)
    - Map Spatial Concept to Bounding Box
    - Map Temporal Concepts to Time Range
MIDAS Agent Framework Design: Organization and Coordination Layer

Organization Layer
- A simple tree structure with a global manager and number of domains is used.
- Each of the domains contains a Manager agent and Worker agents
- Advantage: scalable design that will allow addition of new domains to the overall framework

Coordination Layer
- A broker model is used
- Advantage: unlike matchmaker or a contract-net, this model allows the broker to shoulder some responsibility of finding the right agent and returning the result
MIDAS Agent Framework Design: Constraint Layer and Performatives

Constraint Layer
- By using a tree to represent requests, one can check the goal achievement.
- When all the leaf and intermediary nodes are satisfied, resulting in completion of the root node, the task has been accomplished.

Performatives
- Performatives are the permissible "speech acts" agents use to interact
- Partial set derived from KQML (Knowledge Query and Manipulation Language - UMBC)
- Basic Responses:
  - Error, Sorry
- Query: (Evaluate, AskStatus)
- Capability: (Advertise)
MIDAS: Initialization

MIDAS FRAMEWORK

GLOBAL MANAGER AGENT
MESSAGE BOARD
SEARCH MANAGER AGENT
MESSAGE BOARD
SUBSET MANAGER AGENT
MESSAGE BOARD
SUBSET AGENT

USER QUERY

MESSAGE BOARD
WORKER AGENT
MIDAS: Subset Query

Decompose user request

Post tasks

MIDAS FRAMEWORK

Inference Engine + ONTOLOGIES

SUBSET AGENT

MESSAGE BOARD

SUBSET MANAGER AGENT

GLOBAL MANAGER AGENT

MESSAGE BOARD

SUBSETTING SERVICE

ESML DESCRIPTION FILE
MIDAS: Subset Query

MIDAS FRAMEWORK

USER QUERY

GLOBAL MANAGER AGENT

MESSAGE BOARD

SEARCH MANAGER AGENT

SUBSET MANAGER AGENT

SUBSETTING SERVICE

ESML DESCRIPTION FILE

Check

Check

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MIDAS: Subset Query

MIDAS FRAMEWORK

Select task

Inference Engine + ONTOLOGIES

MESSAGE BOARD

USER QUERY

GLOBAL MANAGER AGENT

MESSAGE BOARD

SUBSET MANAGER AGENT

SERVICE CONCEPT LOOKUP

SUBSETTING SERVICE

MESSAGE BOARD

SUBSET AGENT

ESML DESCRIPTION FILE
MIDAS: Subset Query

Inference Engine

+ ONTOLOGIES

MESSAGE BOARD

SUBSET MANAGER AGENT

SUBSETTING SERVICE

MESSAGE BOARD

SUBSET AGENT

ESML DESCRIPTION FILE
MIDAS: Subset Query

Inference Engine + ONTOLOGIES

Map user request to Subsetting service API

User Query

Message Board

Global Manager Agent

Message Board

Subset Manager Agent

Message Board

Subset Agent

Message Board

Subsetting Service

ESML Description File

Use semantic metadata to map data fields to Subsetting service API

MIDAS FRAMEWORK

MIDAS FRAMEWORK

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MIDAS: Subset Query

USER QUERY

GLOBAL MANAGER AGENT

MESSAGE BOARD

SUBSET MANAGER AGENT

MESSAGE BOARD

SUBSET AGENT

Inference Engine + ONTOLOGIES

Invoke Subsetting Service

SUBSETTING SERVICE

ESML DESCRIPTION FILE

Invoke Subsetting Service

Use syntactic metadata to read the file

MIDAS FRAMEWORK

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MIDAS Summary

• Contains three data preparation/processing domains with services for:
  – Search
  – Data Format Translation
    • Any ESML supported format to Binary
  – Subsetting
• Leverages both Semantic and Structural metadata in ESML
  – Unlike existing hardwired services
• Uses Ontologies and inference engines for reasoning
• Can be adapted for both Web and Grid services
Questions?

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