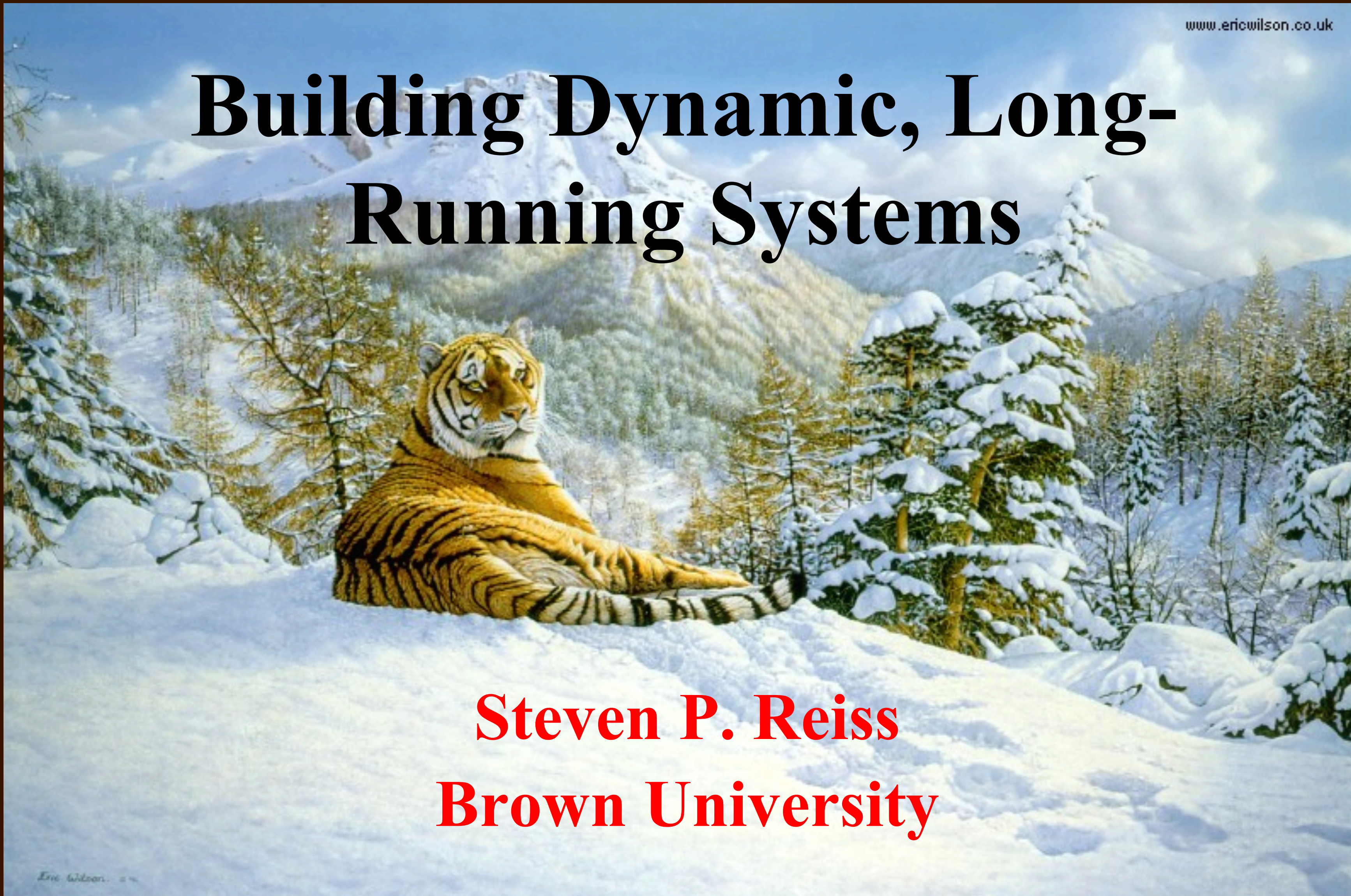
Building Dynamic, Long-Running Systems



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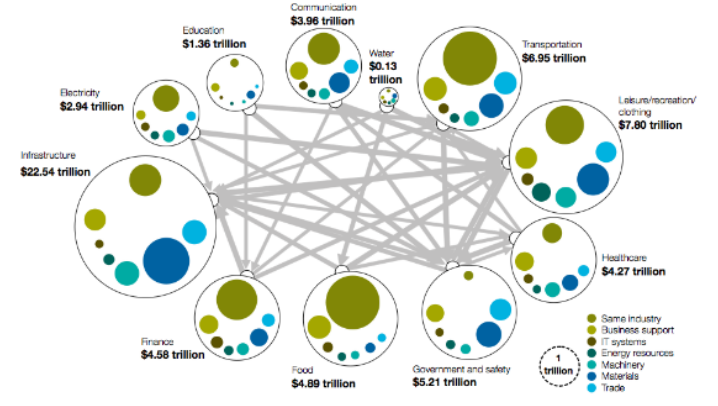
Context

Systems-of-Systems are common place

- Modern applications (waze)
- Applications using multiple data sources
- Applications using multiple back ends
- SoS will be the rule, not the exception



Note: Size of bubbles represents systems' economic values. Arrows represent the strength of systems' interaction.
Source: IBM Institute for Business Value analysis of Organisation for Economic Co-operation and Development (OECD) data.

Figure 1: We live and work within a complex, dynamic and interconnected US$54 trillion system of systems.

Context

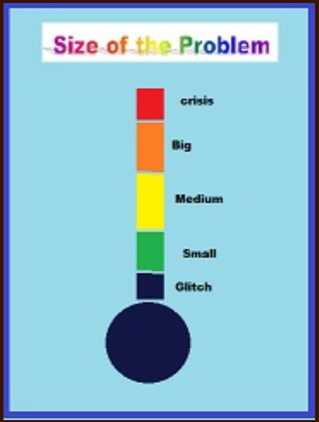
It should be easy to write and maintain such systems

- Handling failure
- Handling evolution
- Dealing with security, privacy, efficiency
- Handling data as well as control
- And not on an ad hoc basis

PROBLEM I

Systems are getting too big for one team to build everything.

- **More reliance on open source solutions**
- **Reliance on outside services**
- **Crowd-sourced programming**
- **Make use of code already written**



PROBLEM II

Long-running systems of systems make use of distributed components that both change and fail.

- **Web services**
- **Micro services**
- **Remote calls**
- **Open source servers**
- **Phones and other devices**

PROBLEM III

Applications should be able to make effective use of dynamically changing computing capabilities.

- **Connections to servers**
- **Availability of local idle cycles**
- **Phones and other portable devices**
- **Automatic reconfiguration**

PROBLEM IV

Applications should be able to make use of the data available from today's many devices.

- Phones
- Health monitors
- Emergency handling
- Cars
- Internet of things

OBJECTIVE

New ways of thinking about long-running programs built over distributed changing systems.

- **Make them straightforward to code**
- **Handle failures, transient and permanent**
- **Handle evolution**
- **Handle data**

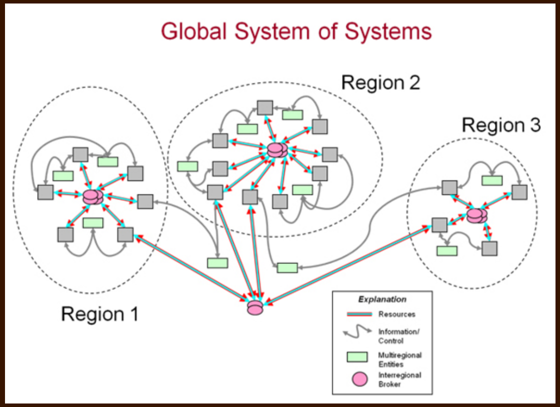
Component-Based Programming

- Appropriate Model for Complex Systems
  - Component can be a system
  - Component can be a piece of a system
  - Component can be a library, class, …
  - Component can be data
- Components
  - Written by one programmer (or a team)
  - Accessible by others
  - Are independent of an application

Component-Based Programming

Provides a basis for systems of systems

- Natural hierarchical way of defining a system
- Failures = component failures
- Evolution = component evolution
- Security = component security



TAIGA (2003)

- Current Trends
  - Web services
  - Peer-to-peer computing
  - Grid computing
  - Common platforms
  - Open source
  - Browser-based applications
- What is the logical progression of combining these?

One World, One Program

- Everything is connected
- Programs communicate to get work done
- Processing is distributed
- Programs depend on each other's data and computation

There is only one program

And it runs everywhere and all the time

Implications

- How do you write a "program"
- How to support large numbers of programmers who don't trust each other
- Security and privacy
- What are the economics of programming
- Sharing data & files as well as code
- Device-independent user interfaces
- The environment is unstable
- How to scale Internet-size

TAIGA

A Framework for a "world program"

- Demonstrate feasibility
- Demonstrate scalability
- Provide solutions to the basic problems
  - How to program
  - How to accommodate multiple programmers
  - How to handle security & privacy
  - Handling failure and evolution
  - Shared data, UI, code, computation, …
  - Making it work economically

world programming

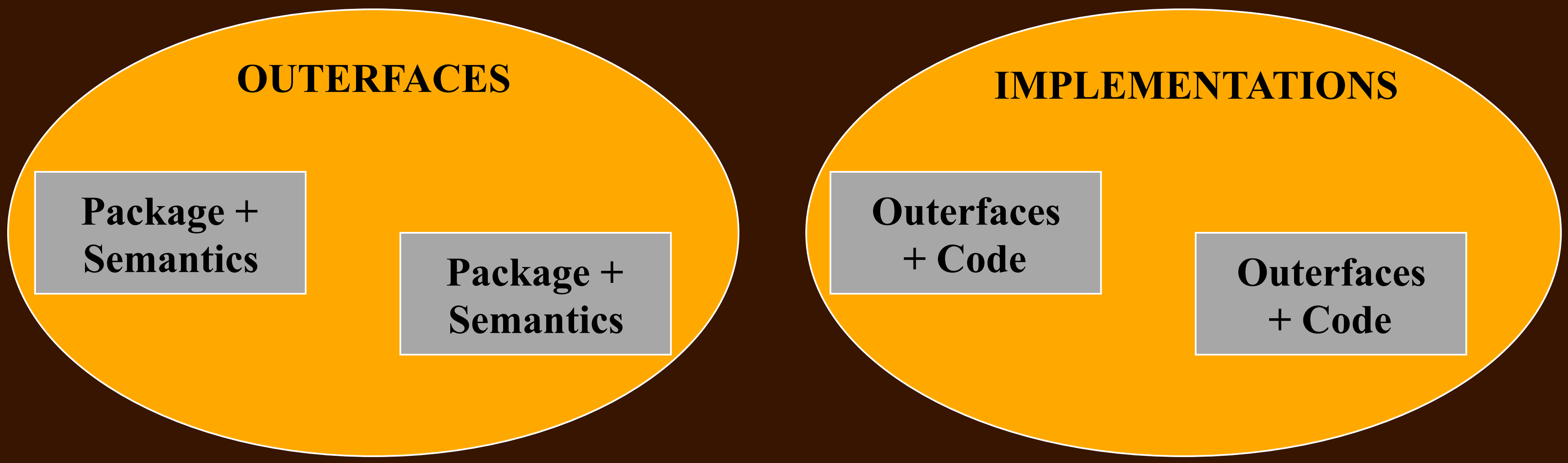
Outerfaces

- Interface to a component
  - Java interface syntax
  - Functions, internal data types, static methods
  - Constructors as default factory
- Semantics of the component
  - Test cases
  - Contracts
- Other constraints
  - Cost model
  - Security model
  - Recovery model

Outerface Example

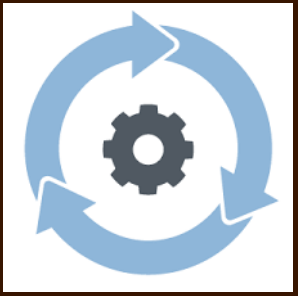
```
outerface edu.brown.cs.newsview.taiga.NewsParser  {
        import java.util.Map;
        description {{
                This outerface parses a URL to determine the country or countries (or
                state or states) that are the topics of the corresponding stories
        }}
        trait { rebind = true; }
        class Parser {
                public static ValueMap scanUrl(String url);
        }
        interface class ValueMap {
                public Map<String,Number> world_values;
                public Map<String,Number> state_values;
        }
        testcase test0 {
                ValueMap rslt = Parser.scanUrl("http://www.nytimes.com/...");
                assert(rslt.get("England")   != null);
                assert(rslt.get("England") > 0.5);
                }
}
```

TAIGA


OUTERFACES
Package + Semantics
Package + Semantics
IMPLEMENTATIONS
Outerfaces + Code
Outerfaces + Code

Implementations

- Define a binding to an outerface
  - Can define multiple outerfaces
  - Does not have to be direct
    - Web service, RPC, External server, Library, …
  - Includes resource files
- Define constraints
  - How it can be used (binding models)
  - Who can use it
  - Security and privacy
  - Cost

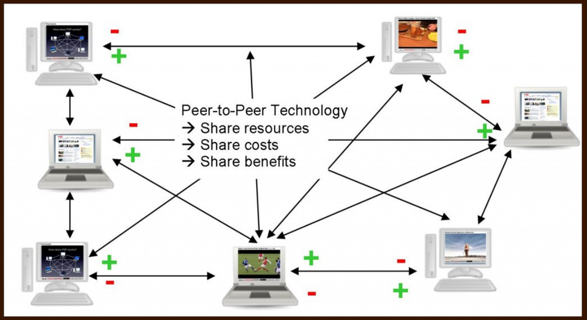


Implementation Example

```
implementation edu.brown.cs.newsview.taiga.QuickParser {

   import edu.brown.cs.newsview.qcrawl.QuickCrawlMap;
   import edu.brown.cs.newsview.qcrawl.QuickPageScan;

   resources "/u/spr/newsview" {
      "data/countries",
      "data/uscities",
      "data/usstates",
      "data/worldcities"
    }

   implements edu.brown.cs.newsview.taiga.NewsParser {
      using class Parser =  edu.brown.cs.newsview.qcrawl.QuickPageScan;
      using interface class ValueMap =  edu.brown.cs.newsview.qcrawl.QuickCrawlMap;
    }

   cost = 50;
}
```

TAIGA Network

- Peer-to-Peer backbone
  - Handles firewalls, failures, routing, …
  - Message-based, command-oriented
  - Simulated direct connections
  - Library system (offers and responses)
- Encrypted point-to-point communication
- Shared facilities
  - Distributed file access
  - Linda-like tuple space

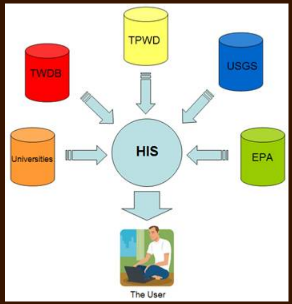


CHALLENGES

- TAIGA provides a starting point
  - How to upgrade it to handle today's systems of systems
- Handling Data as first class objects
  - Data can be generated by anyone
  - Data can be used as needed
  - Data sources will evolve
  - Data sources will come and go

Data Components

- Today's systems depend on data
  - Waze, health data in an emergency, …
  - Data is available in many forms
- Standardize data in terms of components
  - Data Interface describes the data
  - Data Provider implements that interface



DataFaces

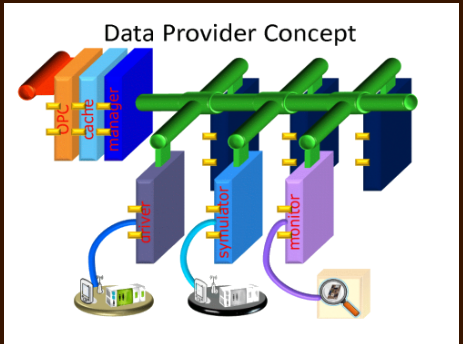
- Syntactic Definition
  - Available fields (structure/table definition)
  - Filters, aggregations, …
- Semantic Definitions
  - Units, consistency properties, …
- Other Considerations
  - Costs
  - Security, privacy, …

DataFace Example

```
dataface edu.brown.cs.loadview.taiga.MachineLoad {
  String host_name;
  String host_id;
  double load_average;
  long   up_time;
  int     num_process;
  long   total_memory;
  long   memory_used;
  long   total_swap;
  long   swap_used;

  units {
    up_time : minutes,  total_memory : bytes,   memory_used : bytes, total_swap : bytes, swap_used : bytes
   }
  restricts {
    0 <= load_average;
    0 <= up_time;
    0 <= num_process;
    0 <= total_memory;
    0 <= memory_used <= total_memory;
    0 <= total_swap;
    0 <= swap_used <= total_swap
   }
}                    // end of dataface MachineLoad
```

Data Provider

- Provides access to the data
  - Returns dataface-determined structure
  - Handles unit conversions, mappings, etc.
  - Filter determines applicability
- Multiple providers are supported
- Providers register with the system



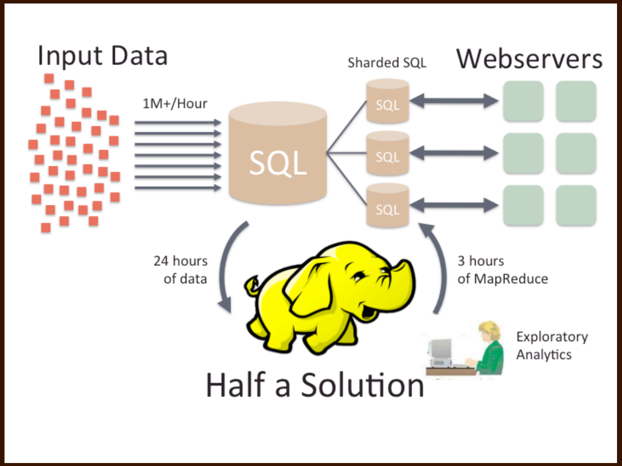
Data Provider Example

```
dataface implementation edu.brown.cs.loadview.taiga.LinuxMachineLoad {

  application edu.brown.cs.loadview.impl.LinuxLoadChecker;
  using edu.brown.cs.loadview.impl.LinuxMachineLoad;

  implements edu.brown.cs.loadview.taiga.MachineLoad {
    using host_name = host_name;
    using host_id = host_id;
    using load_average = load_average;
    using up_time = getUpTime();
    using num_process = num_processes;
    using total_memory = total_memory;
    using memory_used = memory_used;
    using total_swap = total_swap;
   }

  units {
    up_time : seconds,
    total_memory : kilobytes,
    memory_used : kilobytes,
    total_swap : kilobytes,
    swap_used : kilobytes
   }

}                 // end of dataface implementation LinuxMachineLoad
```

Data Access

- Applications access datafaces by queries
  - Stream-based SQL language
  - Translated into FILTER/AGGREGATE
- Aggregation, filtering handled by system
  - Stream-based data processing
  - Client returned the aggregated fields

Sample Queries



- Query

  SELECT *
  FROM MachineLoad
  WHERE up_time > 30

- Get the load structure from all machines
  - Given machine has been up > 30 minutes
  - Gets the data as it is generated

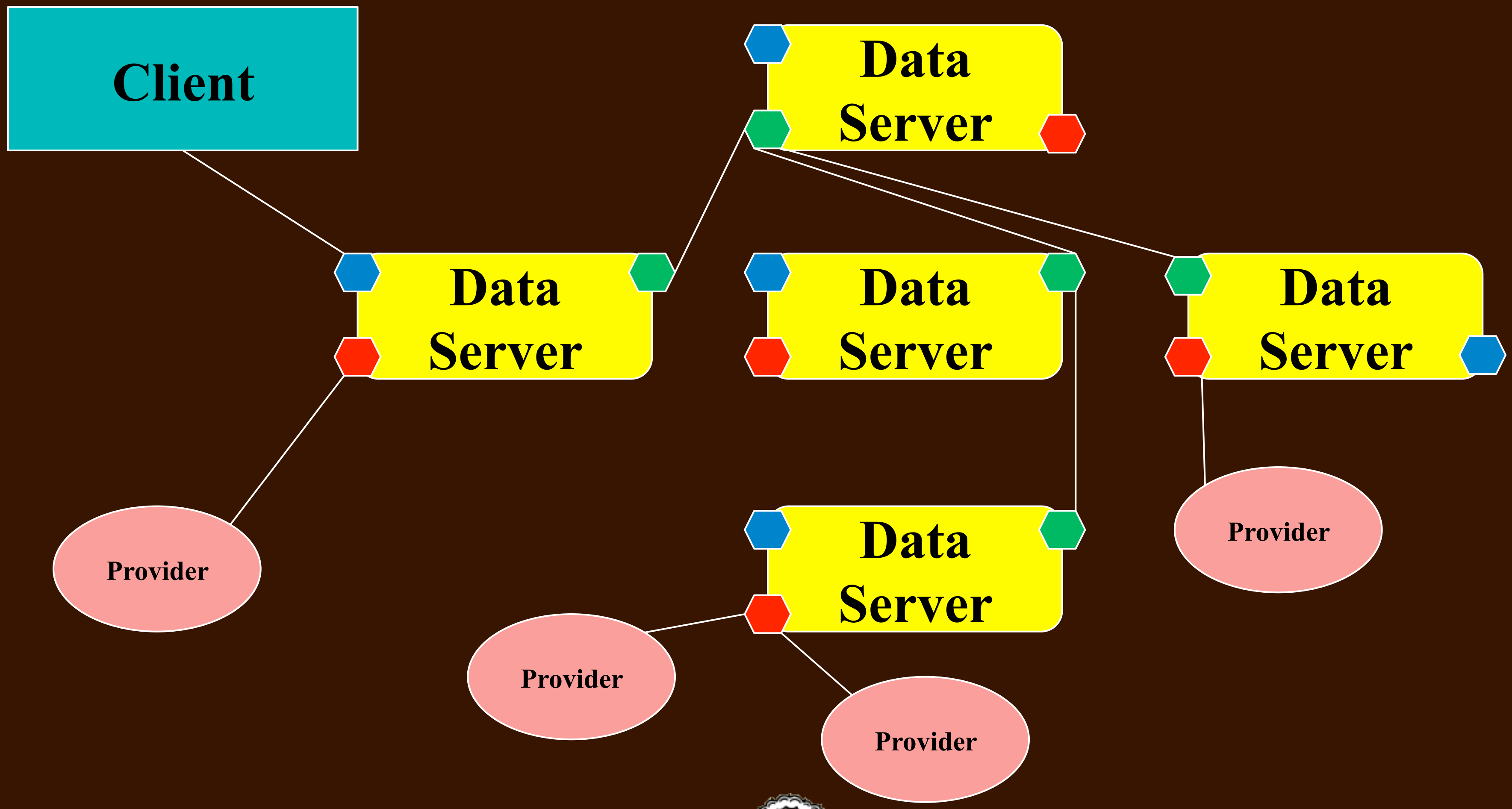
Sample Query

- **COMPILED QUERY:**

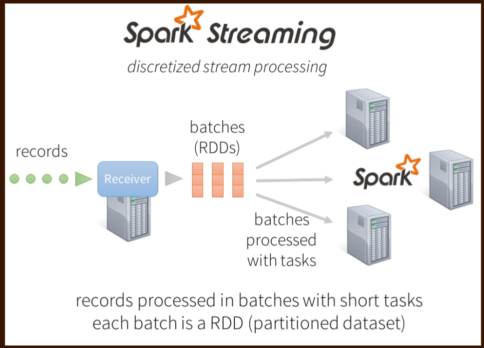
```
<DFACEQUERY WINDOW='60000' UID='sprtestquery1'>
        <DATAFACE>edu.brown.cs.loadview.taiga.MachineLoad</DATAFACE>
        <ACTION TYPE='FILTER'>
                <FIELD MIN='5' METHOD='getUpTime' />
        </ACTION>
        <ACTION TYPE='AGGREGATE‘>
           <GROUPBY METHOD='getHostName' SET='setHostName' VALUE='*' />
           <GROUPBY METHOD='getHostId' SET='setHostId' VALUE='*' />
           <COMPUTE METHOD='getLoadAverage' SET='setLoadAverage'
        OP='AVERAGE' />
           <COMPUTE METHOD='getUpTime' SET='setUpTime' OP='MAX' />
           <COMPUTE METHOD='getNumProcess' SET='setNumProcess' OP='SUM' />
           <COMPUTE METHOD='getTotalMemory' SET='setTotalMemory'
        OP='SUM' />
           <COMPUTE METHOD='getMemoryUsed' SET='setMemoryUsed'
                OP='SUM' />
           <COMPUTE METHOD='getTotalSwap' SET='setTotalSwap' OP='SUM' />
           <COMPUTE METHOD='getSwapUsed' SET='setSwapUsed'
                OP='AVERAGE' />
        </ACTION>
</DFACEQUERY>";
```

- **RESULT**
  - **Single MachineLoad generated every 60 seconds**
  - **Ignore host, hostid; compute the rest**

Data Processing



Data Processing

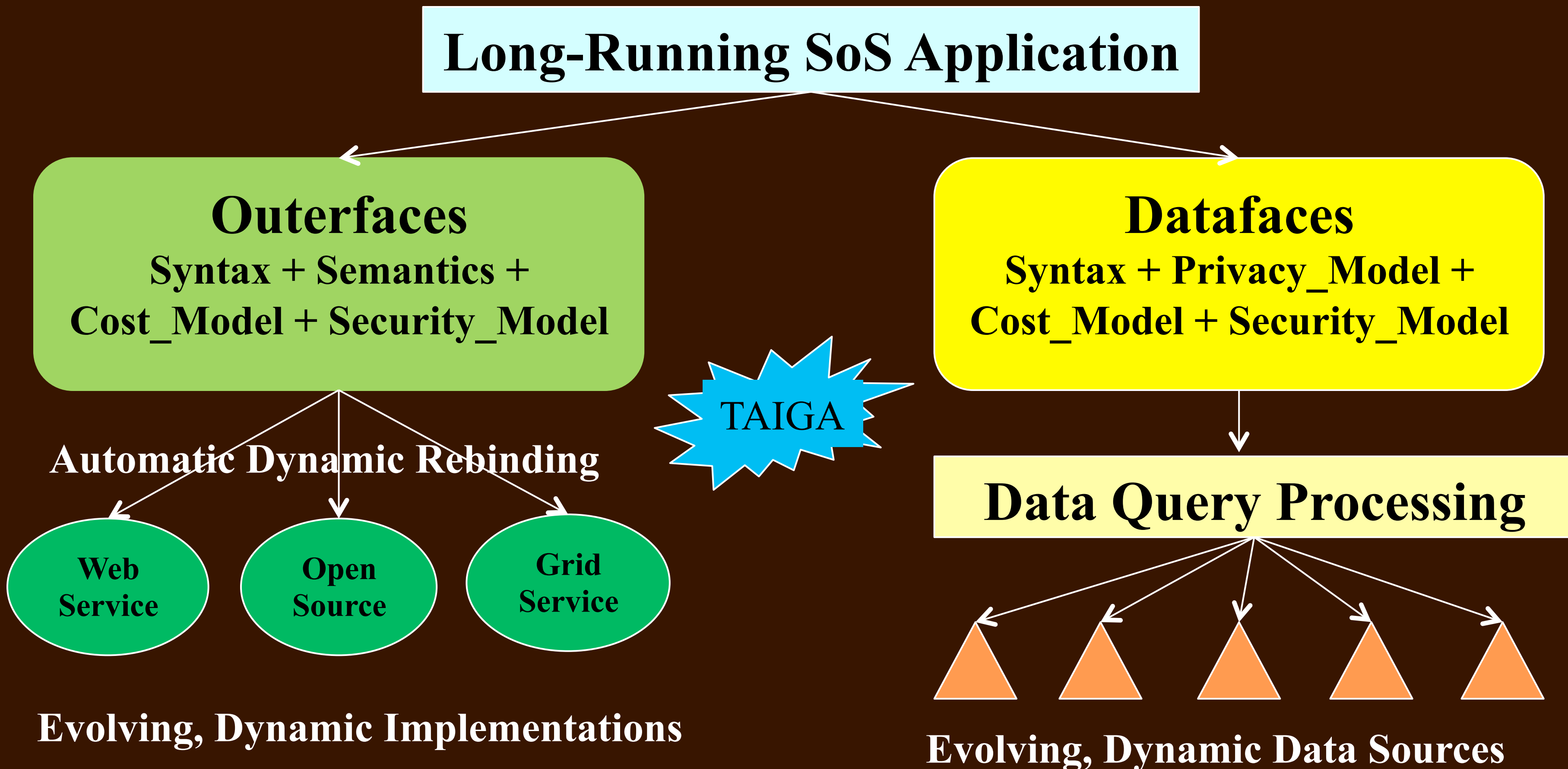


- Make use of the underlying network
  - Sets up a tree of data servers
  - One or more per ring
- Servers create a tree for each query
  - Aggregation and filtering done locally
    - When possible
  - Timers + notification from children
- Treat the network as a stream processor
  - Stream query language (SQL-like)

On-Going Work

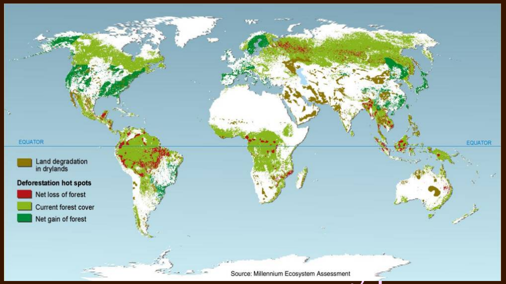
- Efficient Query Processing
  - Scalable
- Handling failure and evolution
- Security and Privacy
  - Data provider can limit access
    - Based on filter
    - Based on minimum aggregation count
  - Data provider can provide approximate results (Differential privacy)

Dynamic Long-Running Systems



Taiga Futures

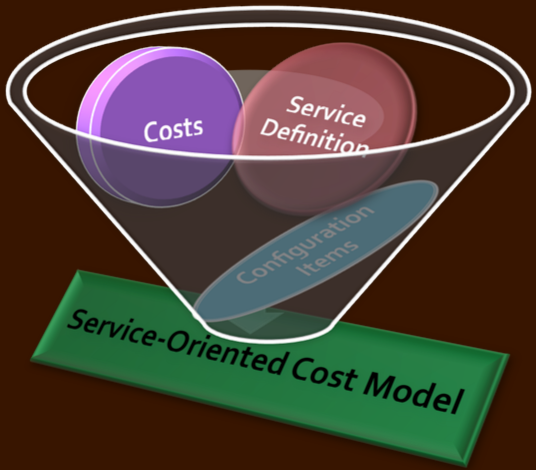
- Alternative semantic definitions
- Better cost models
  - Allow dynamic reconfiguration
- Better security models
- Enhanced binding models
  - RESTful interfaces, micro services
- Robustness and scalability
- Fully integrating data and control
- Where do we go from here?



Questions and Comments

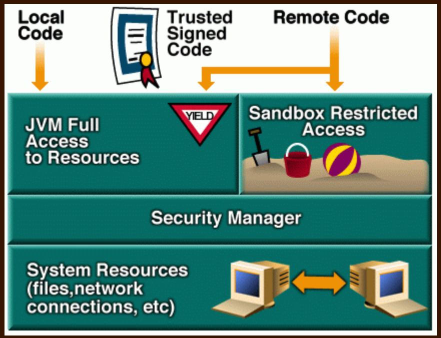
Cost Model

- Takes multiple factors into account
  - Performance (on test cases) (CPU/memory)
  - Binding type (library, server, grid, web)
  - Traits
  - Cost of implementation
- Designed for extensibility



Security Model

- Based on Java Security Model
  - Defines what operations can/can't be done
  - Files, sockets, system info, class loading, …
- Validated when testing
  - Testing done in a sandbox environment
- Security context for library calls
  - Used to map resource files as well
- Security context for applications
  - Sandboxed when possible

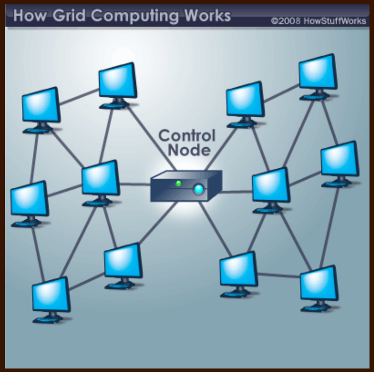


Binding Model

- TAIGA binds implementations to outerfaces
  - Binding is an explicit operation
    - Requires passing the tests and constraints
    - Generates a saved version of the implementation
  - Done automatically on first use
- TAIGA finds implementations at run time
  - Using the economic model
  - Binds on the fly
- Same user code works for all bindings
  - Programmer codes to outerface
  - Downloaded library, server, web service, grid

Grid-Binding

- Finds a node to run the server on
  - Send out request to servers
  - With pertinent information
- Servers
  - Look at request and decide if they want it
  - Respond yes/no (or ignore)
- Binder chooses accepting server
  - Runs the service there



Type Model

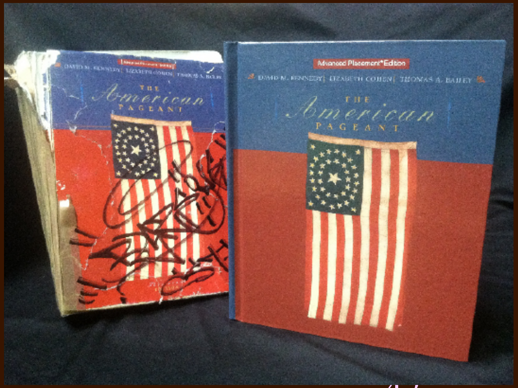
- TAIGA maintains type consistency
  - Across implementations
  - Objects can be used with expected semantics
  - Collections are supported
    - Immutable if Java types
    - Mutable if TAIGA types
  - Types are mapped on calls and returns
- Makes coding remote applications easier

Failure Model

- Complex systems fail in different ways
  - Network failures
  - Server failures
  - System failures (wrong result, unexpected exceptions, contract failure, timeouts)
  - All can be viewed as component failures
- Application should continue working in the presence of failures

TAIGA Rebinding

- When an implementation fails
  - Either explicitly (call fails)
  - Or implicitly (contract fails, exception)
- TAIGA will rebind the outerface
  - Unbinds the original binding
  - Applies the cost model to find an implementation
  - Validates the new implementation
  - Binds the new implementation



Outerface Example

```
outerface edu.brown.cs.webview.taiga.WebManager {

   description {{
      This outerface manages a set of files for the webview application, ensuring
      that they do not get too long.  A transfer record is added to a file when it
      does exceed the 1M length limit
    }}

   trait { rebind=true; }

   class FileManager {
      static public String getCurrentFile();
      static public String getFileForDate(long date);
    }

   testcase Test0 {{
      public static void test() {
       FileManager.getCurrentFile();
       TaigaTesting.success();
       }
    }}

}    // end of outerface WebManager
```

Outerface Example

```
outerface edu.brown.cs.newsview.taiga.NewsCrawler {
  import java.util.Map;
  description {{  This outerface periodically crawls a particular web site for news.  }}
  trait { rebind=true; }
  requires edu.brown.cs.newsview.taiga.NewsParser;

  class Crawler {
    public Crawler(String baseurl,int level);
    public void addRoot(String root);
    public void setValidEnds(String ends);
    public void addIgnoreLinkPattern(String pat);
    public void setHome(String home);
    public void setTimeLimit(long time);
    public void setBase(String base);
    public ResultMap getValues();
   }

  interface class ResultMap {
    public Map<String,Number> world_values;
    public Map<String,Number> state_values;
   }
  cost { bind : GRID >>= 1, SERVER >>= 4; }
}
```

Outerface Example

```
outerface edu.brown.cs.newsview.taiga.NewsClient {
  description {{   …….  }}
  import java.util.*;
  requires edu.brown.cs.newsview.taiga.NewsCrawler, edu.brown.cs.newsview.taiga.NewsManager;
  trait { rebind=true; }
  class Client {
    model { Map<String,Number> source_set  }
    public Client()
        model { source_set = new HashMap<String,Number>(); };
    public void addSource(String name,double weight)
        model { source_set.put(name,weight); };
    public void removeSource(String name)
        model { source_set.remove(name); };
    public ClientValueMap getValues();
   }
  interface class ClientValueMap {
    public Map<String,Number> world_values;
    public Map<String,Number> state_values;
   }
}
```

Implementation Example

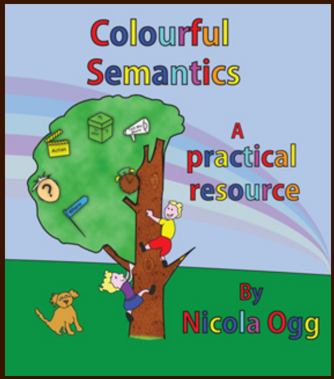
```
implementation edu.brown.cs.webview.taiga.SimpleManager {
  using edu.brown.cs.webview.recorder.RecorderManager;
   implements edu.brown.cs.webview.taiga.WebManager {
      using class FileManager =
              edu.brown.cs.webview.recorder.RecorderManager;
   }
   cost = 40;
   available *;
}
```

Security Extensions

- Peer-to-peer backbone has to be secure
  - Clients are who they say they are
  - Clients are running proper code
  - Clients are limited to particular domains
  - Add a notion of identity
- Create a private version of TAIGA
  - In addition to the public, everywhere version

Semantic Definitions

- Test cases & contracts are limiting
  - Broader than formal specifications
  - But still difficult to define in many cases
- Going beyond test cases
  - Partial specifications
  - Pseudo-code, frameworks, sketches, …
  - Interaction with the programmer



Deploying at Scale

- TAIGA is a prototype
  - P2P network needs work
  - Unbinding of libraries not clean
  - Sandboxed execution of tests
  - Can be much more efficient
  - No phone-based implementation
- Needs to work with 1000s of nodes
  - Only tested with ~100
  - Generally running with ~10