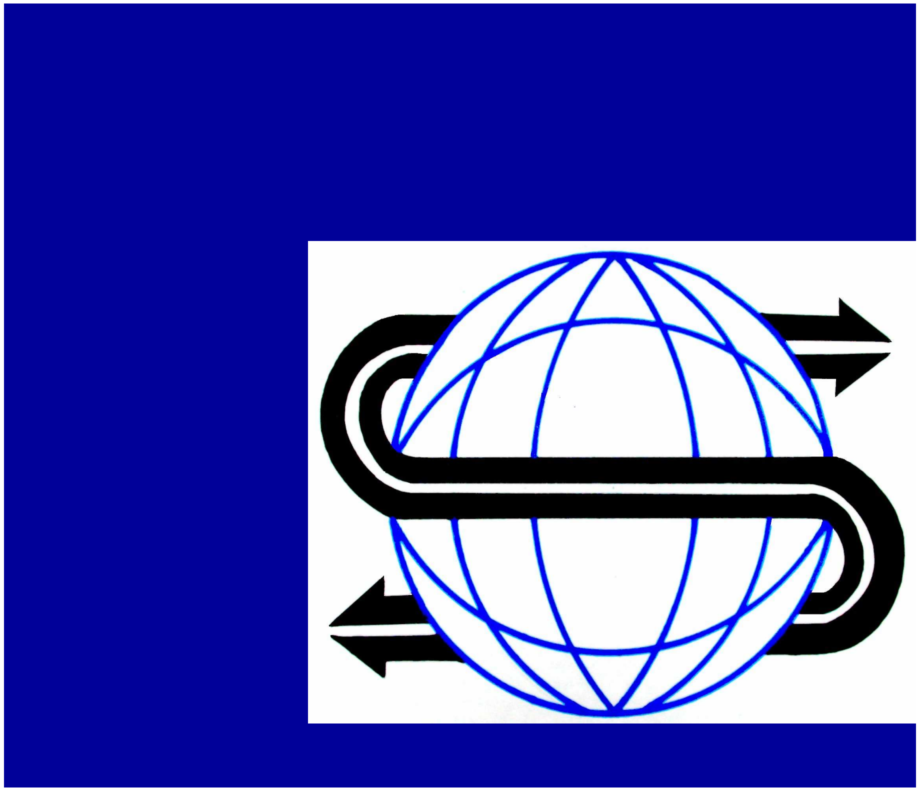


Optimization Services (OS)

-- A Framework for Optimization Software

-- A Computational Infrastructure

-- The Next Generation NEOS

-- The OR Internet

Jun Ma

Dissertation Defense

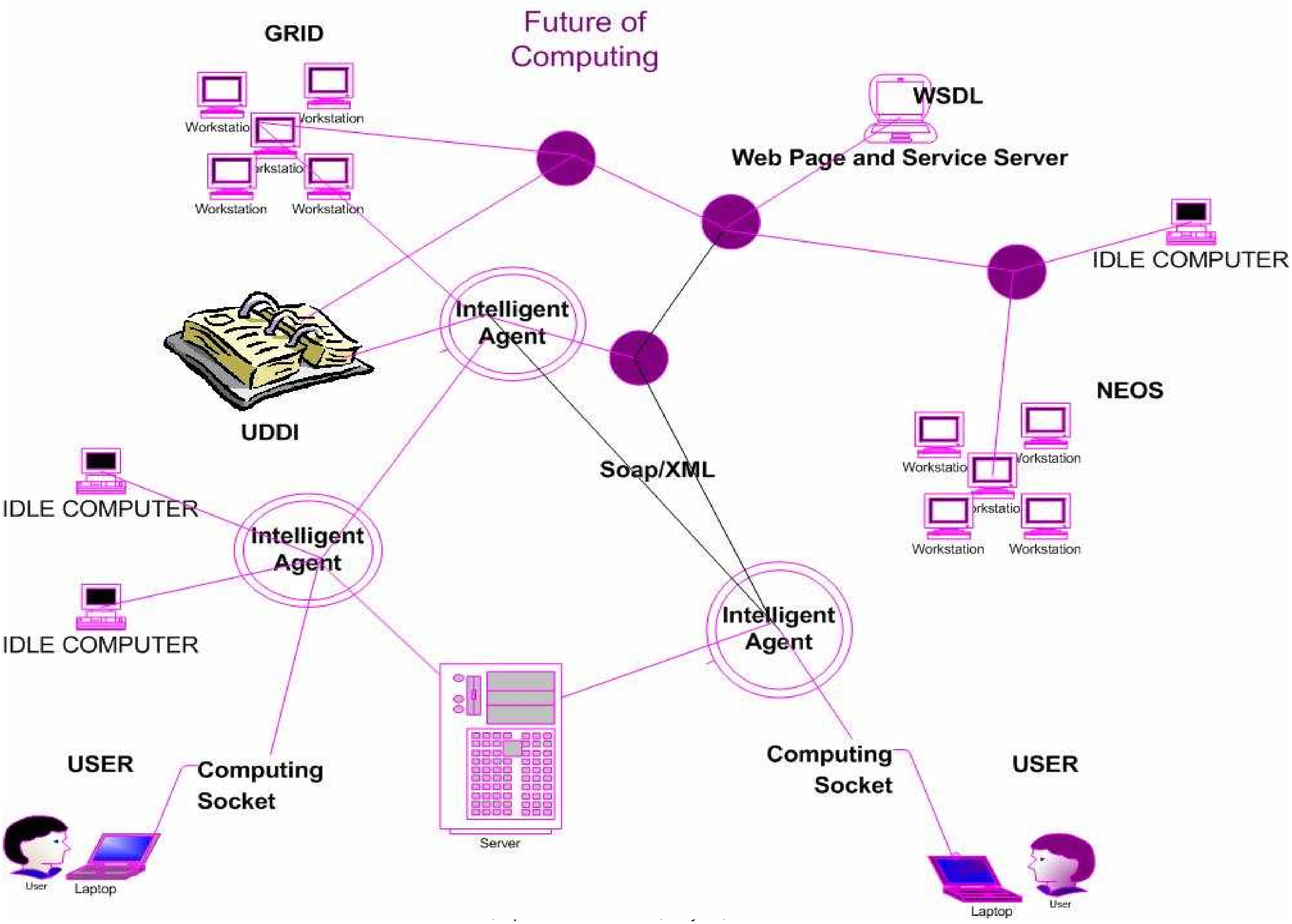
Industrial Engineering and Management Sciences
Northwestern University
05/06/2005

OUTLINE

1. **Motivations**
2. Demonstration
3. Optimization Services and Optimization Services Protocol
4. Optimization System Background
5. Computing and Distributed Background
6. Optimization Services Protocol - Representation
7. Optimization Services Protocol - Communication
8. Optimization Services Protocol - Registry
9. Optimization Services modeling Language (OSmL)
10. Future and Derived Research

Motivation

Future of Computing



Motivation

But how… with so many type of components

1. Modeling Language Environment (MLE)

   (AIMMS, AMPL, GAMS, LINGO, LPL, MOSEL, MPL, OPL, OSmL)

2. Solver

   (Too many)

3. Analyzer/Preprocessor

   (Analyzer, MProbe, Dr. AMPL)

4. Simulation

   (Software that does heavy computation, deterministic or stochastic)

5. Server/Registry

   (NEOS, BARON, HIRON, NIMBUS, LPL, AMPL, etc.)

6. Interface/Communication Agent

   (COIN-OSI, CPLEX-Concert, AMPL/GAMS-Kestrel, etc.)

7. Low Level Instance Representation

   (Next page)

Motivation

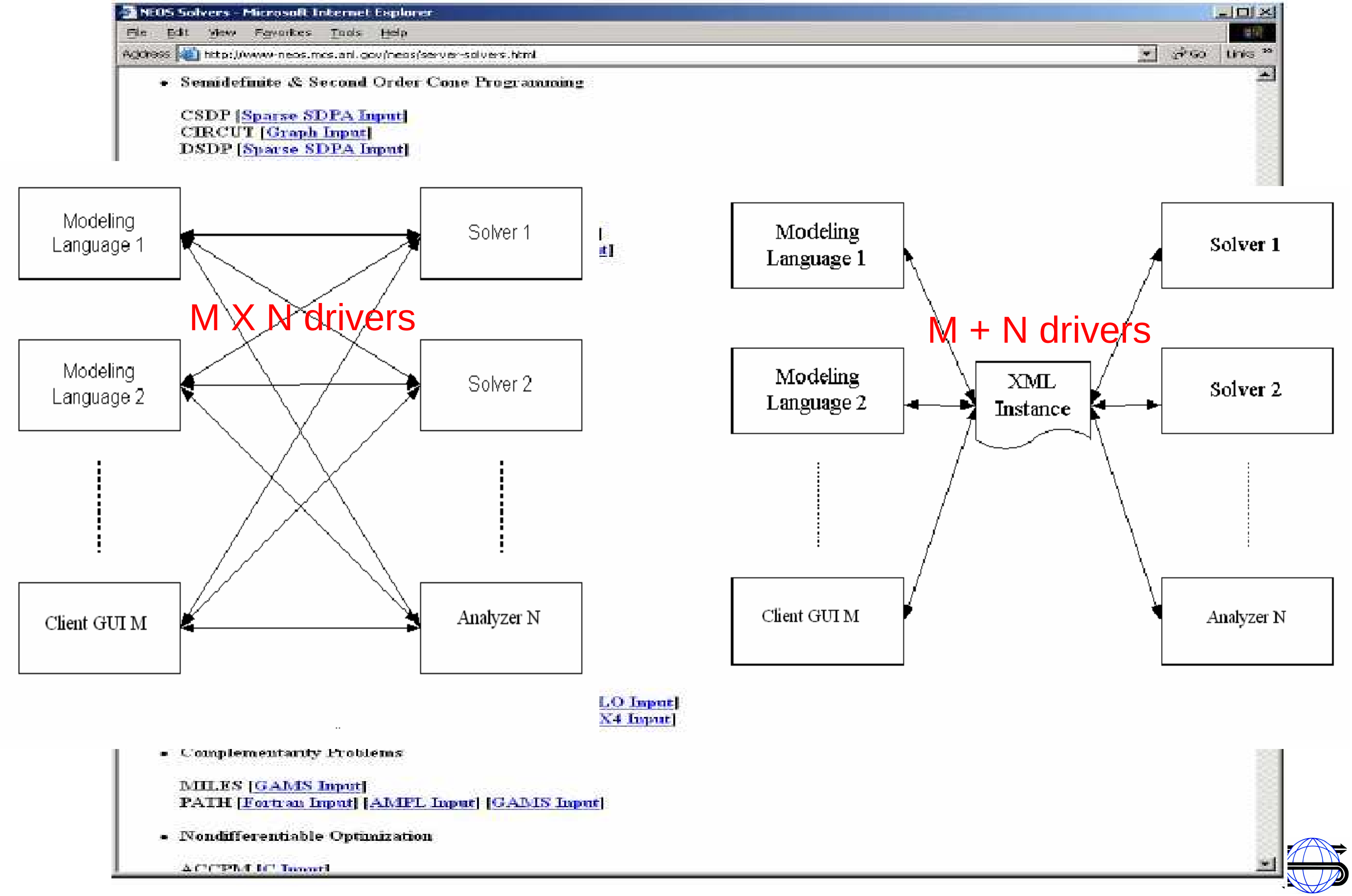
But how… with so many optimization types and representation formats

Linear Programming Quadratic Programming Mixed Integer Linear Programming	MPS, xMPS, LP, CPLEX, GMP, GLP, PuLP, LPFML, MLE instances
Nonlinearly Constrained Optimization Bounded Constrained Optimization Mixed Integer Nonlinearly Constrained Optimization Complementarity Problems Nondifferentiable Optimization Global Optimization	MLE instances SIF (only for Lancelot solver)
Semidefinite & Second Order Cone Programming	Sparse SDPA, SDPLR
Linear Network Optimization	NETGEN, NETFLO, DIMACS, RELAX4
Stochastic Linear Programming	sMPS
Stochastic Nonlinear Programming	None
Combinatorial Optimization	None (except for TSP input, only intended for solving Traveling Sales Person problems.
Constraint and Logic Programming	None
Optimization with Distributed Data	None
Optimization via Simulation	None

OSiL

Motivation

Look at the NEOS server Web site



- Semidefinite & Second Order Cone Programming

CSDP [Sparse SDPA Input]
CIRCUT [Graph Input]
DSDP [Sparse SDPA Input]

LO Input]
X4 Input]

- Complementarity Problems

MILES [GAMS Input]
PATH [Fortran Input] [AMPL Input] [GAMS Input]

- Nondifferentiable Optimization

ACCPM [C Input]

Motivation

As if it’s not bad enough …

1. Tightly-coupled implementation (OOP? Why not!)

2. Various operating systems

3. Various communication/interfacing mechanisms

4. Various programming languages

5. Various benchmarking standards

Motivation

Now…

- **The key issue is communication, not solution!**
- **… and Optimization Services is intended to solve all the above issues.**

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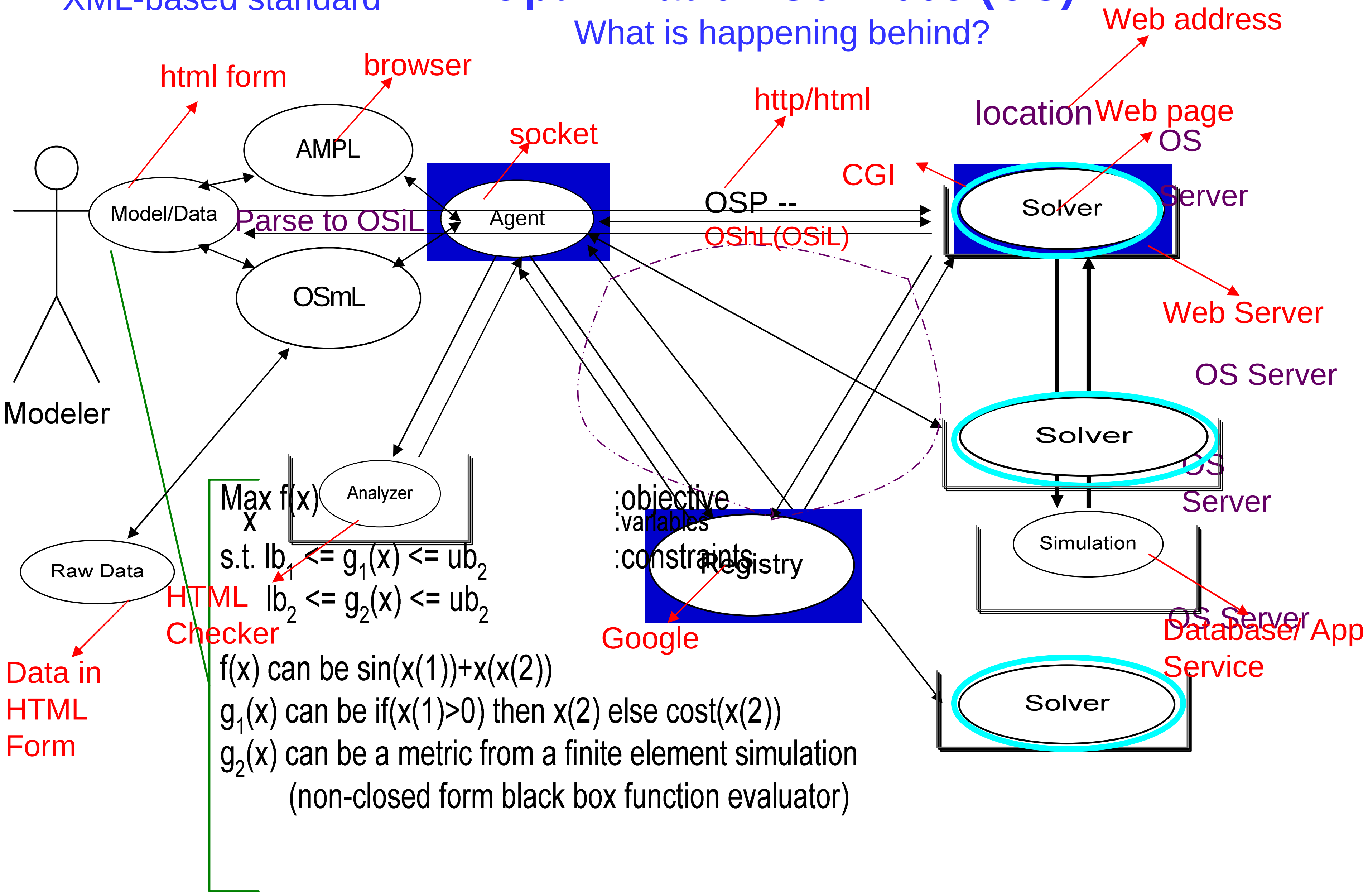
XML-based standard

Optimization Services (OS)

What is happening behind?



$\max\limits_{x} f(x)$

s.t. $lb_1 <= g_1(x) <= ub_2$

$lb_2 <= g_2(x) <= ub_2$

f(x) can be sin(x(1))+x(x(2))

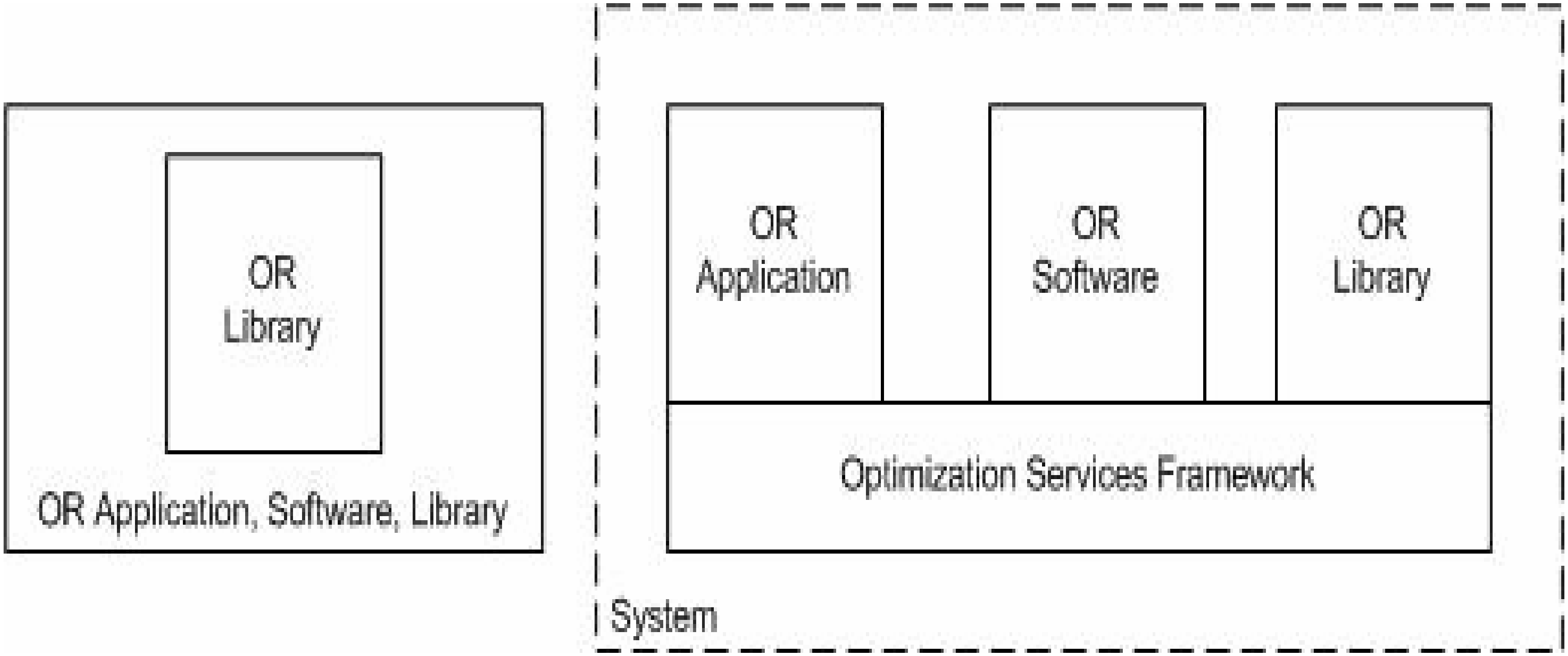
$g_1(x)$ can be if(x(1)>0) then x(2) else cost(x(2))

$g_2(x)$ can be a metric from a finite element simulation

(non-closed form black box function evaluator)

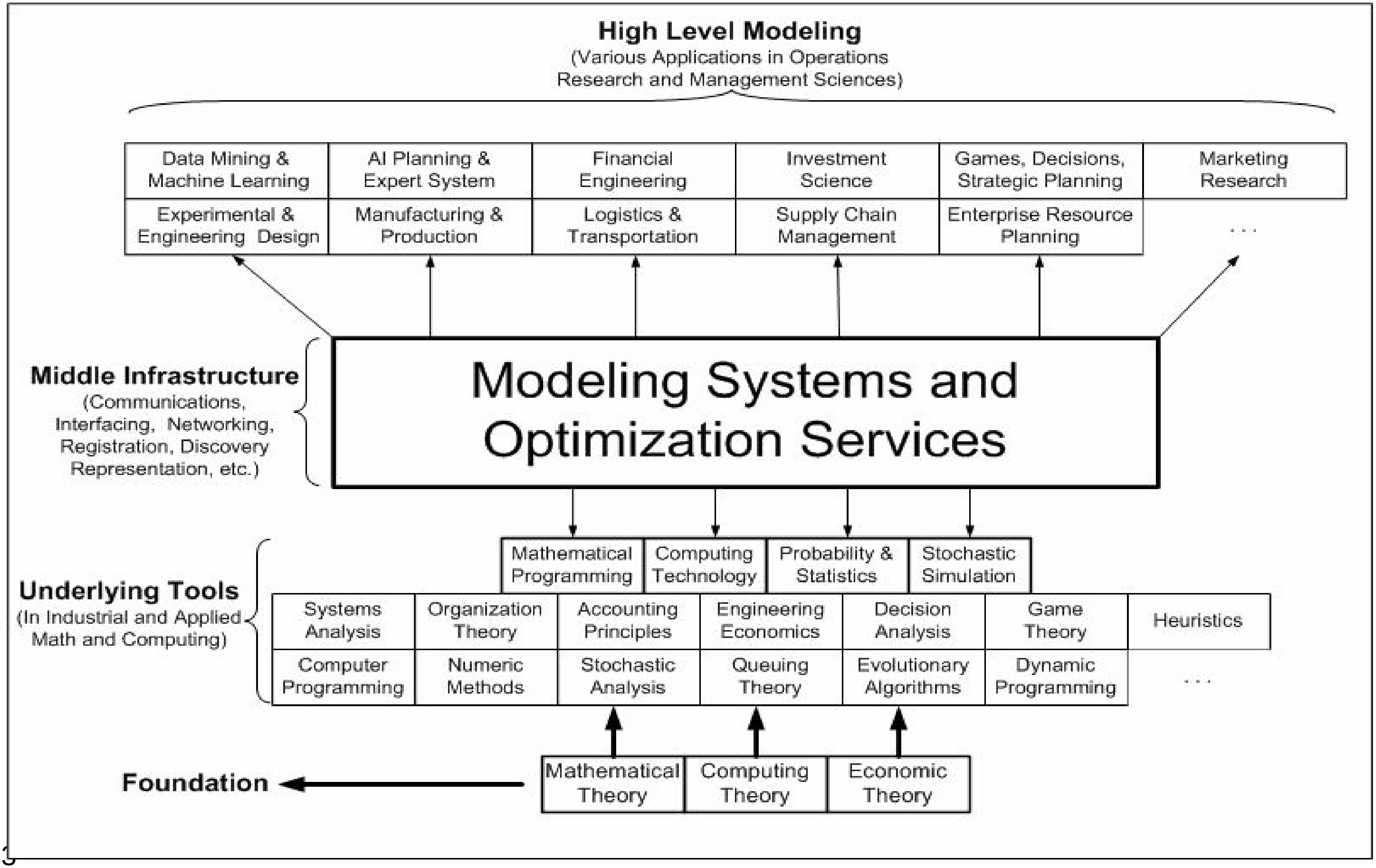
Optimization Services

What is it? – A framework for optimization software


OR Library
OR Application, Software, Library
OR Application
OR Software
OR Library
Optimization Services Framework
System

Optimization Services

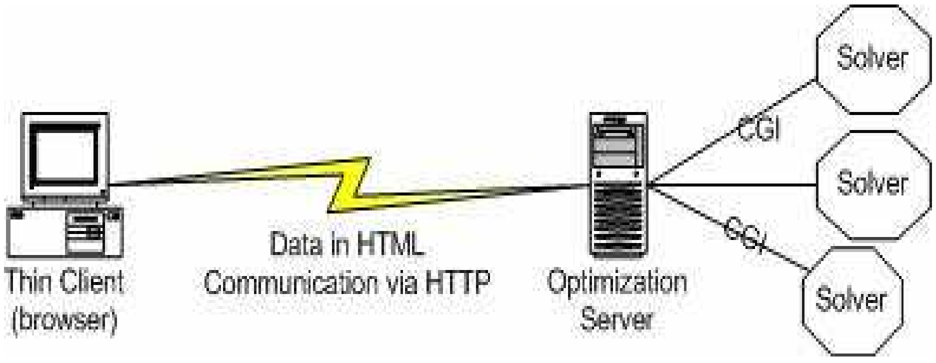
What is it? – A computational infrastructure

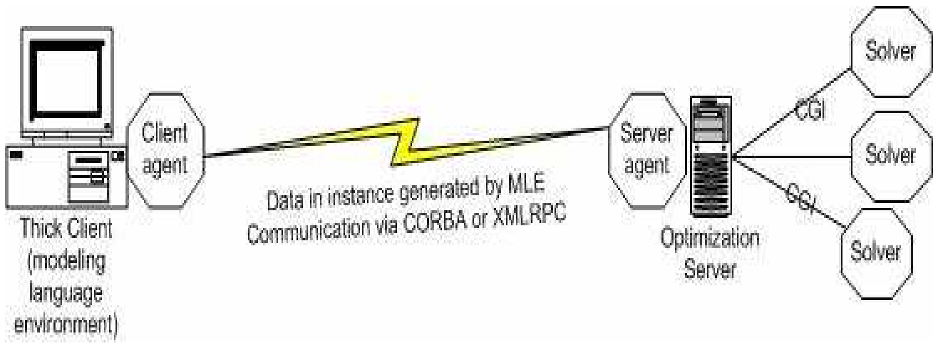


Optimization Services

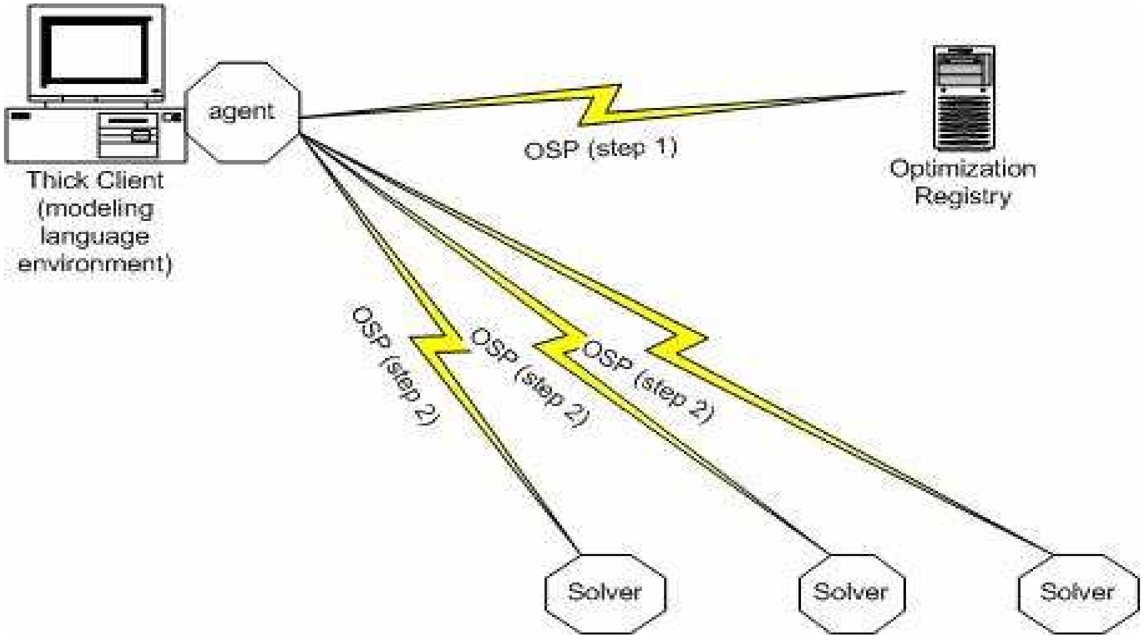
What is it? – The next generation NEOS

NEOS
Server for Optimization



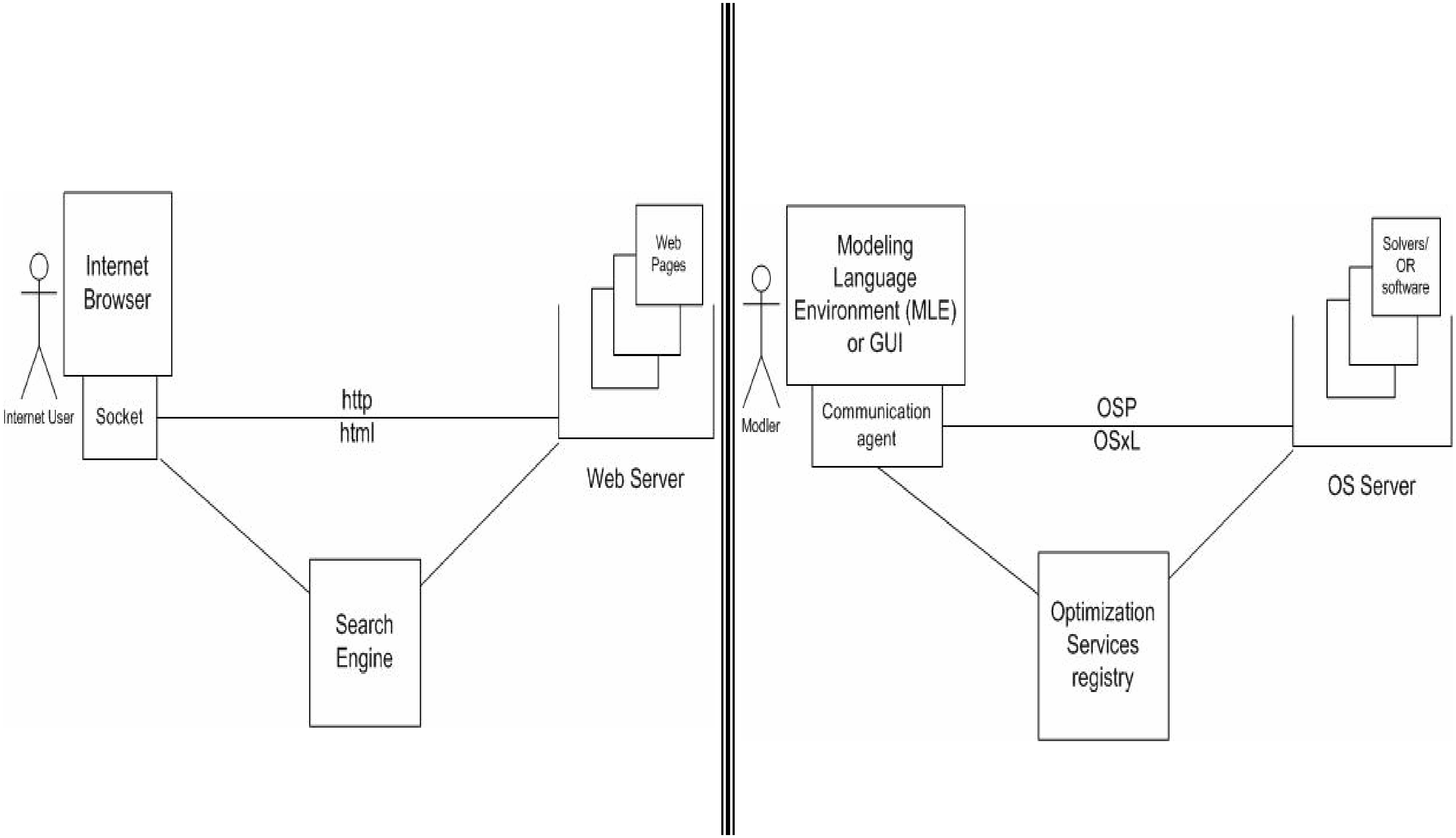


- •The NEOS server and its connected solvers uses the OS framework.
- •NEOS accepts the OSiL and other related OSP for problem submissions
- •NEOS becomes an OS compatible meta-solver on the OS network
- •NEOS hosts the OS registry



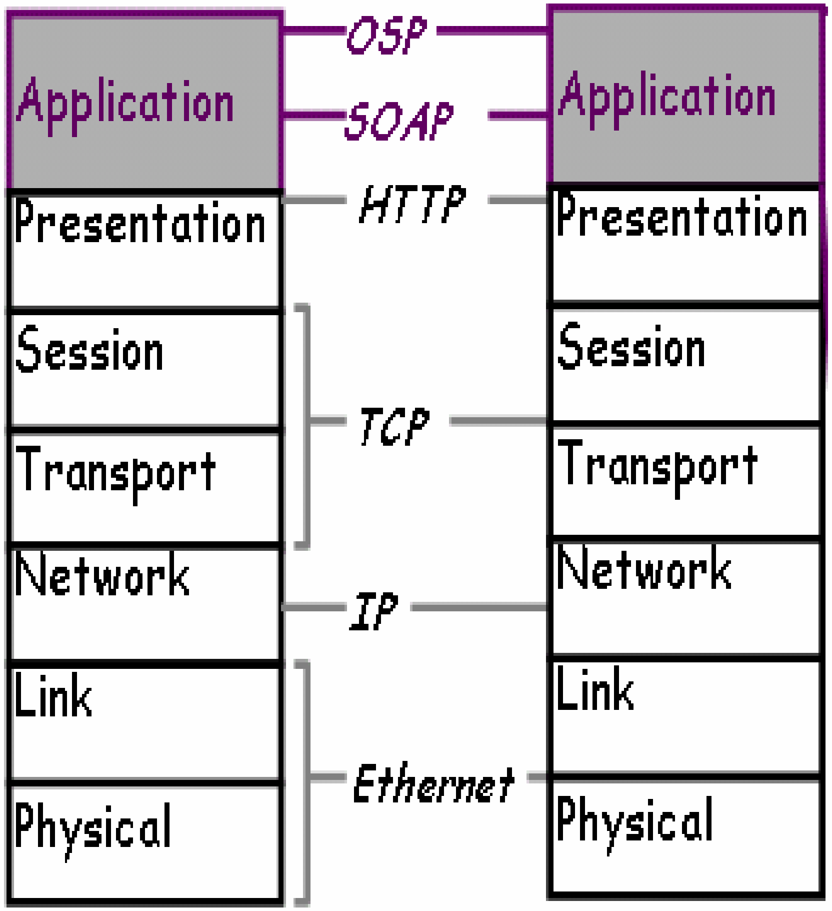
Optimization Services

What is it? – The OR Internet

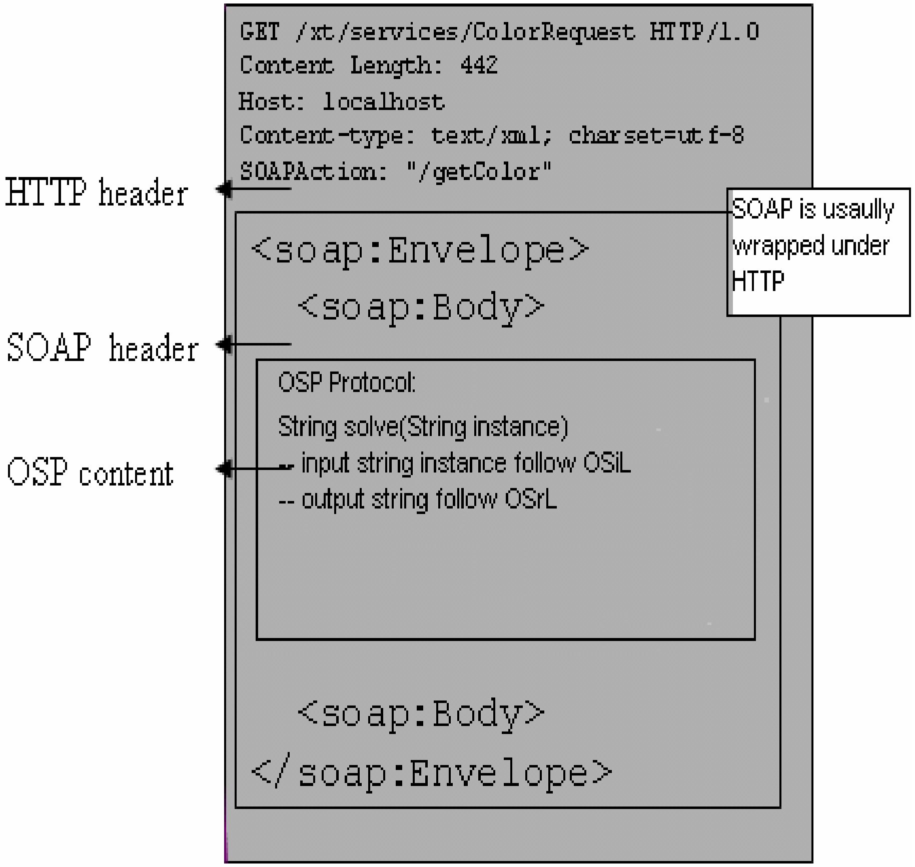


Optimization Services Protocol (OSP)

What is it? – Application level networking protocol
– Interdisciplinary protocol between CS and OR



The 7-layer OSI Model   The 4-layer Internet model



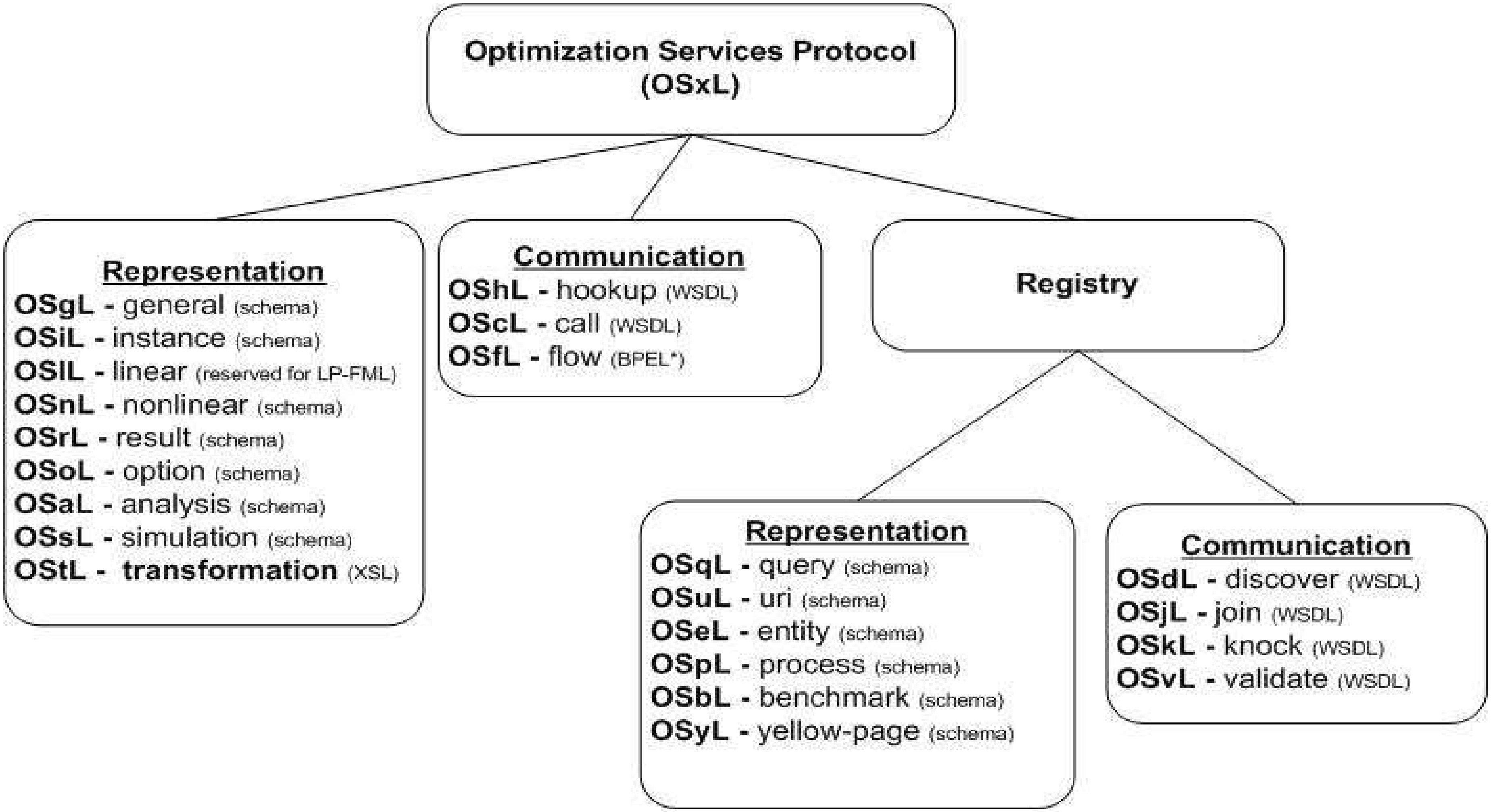
```
GET /xt/services/ColorRequest HTTP/1.0
Content Length: 442
Host: localhost
Content-type: text/xml; charset=utf-8
SOAPAction: "/getColor"

<soap:Envelope>
  <soap:Body>
    OSP Protocol:
    String solve(String instance)
    -- input string instance follow OSiL
    -- output string follow OSrL

  <soap:Body>
</soap:Envelope>
```

Optimization Services Protocol (OSP)

What does the protocol involve? – 20+ OSxL languages



Optimization Services Protocol (OSxL)

Representation

- **OSgL** - general (schema)
- **OSiL** - instance (schema)
- **OSlL** - linear (reserved for LP-FML)
- **OSnL** - nonlinear (schema)
- **OSrL** - result (schema)
- **OSoL** - option (schema)
- **OSaL** - analysis (schema)
- **OSsL** - simulation (schema)
- **OStL** - **transformation** (XSL)

Communication

- **OShL** - hookup (WSDL)
- **OScL** - call (WSDL)
- **OSfL** - flow (BPEL*)

Registry

Representation

- **OSqL** - query (schema)
- **OSuL** - uri (schema)
- **OSeL** - entity (schema)
- **OSpL** - process (schema)
- **OSbL** - benchmark (schema)
- **OSyL** - yellow-page (schema)

Communication

- **OSdL** - discover (WSDL)
- **OSjL** - join (WSDL)
- **OSkL** - knock (WSDL)
- **OSvL** - validate (WSDL)

***OSmL:** a modeling language and NOT an Optimization Services Protocol
***Letters not currently used:** w, z
***BPEL:** Business Process Execution Language for flow orchestration.

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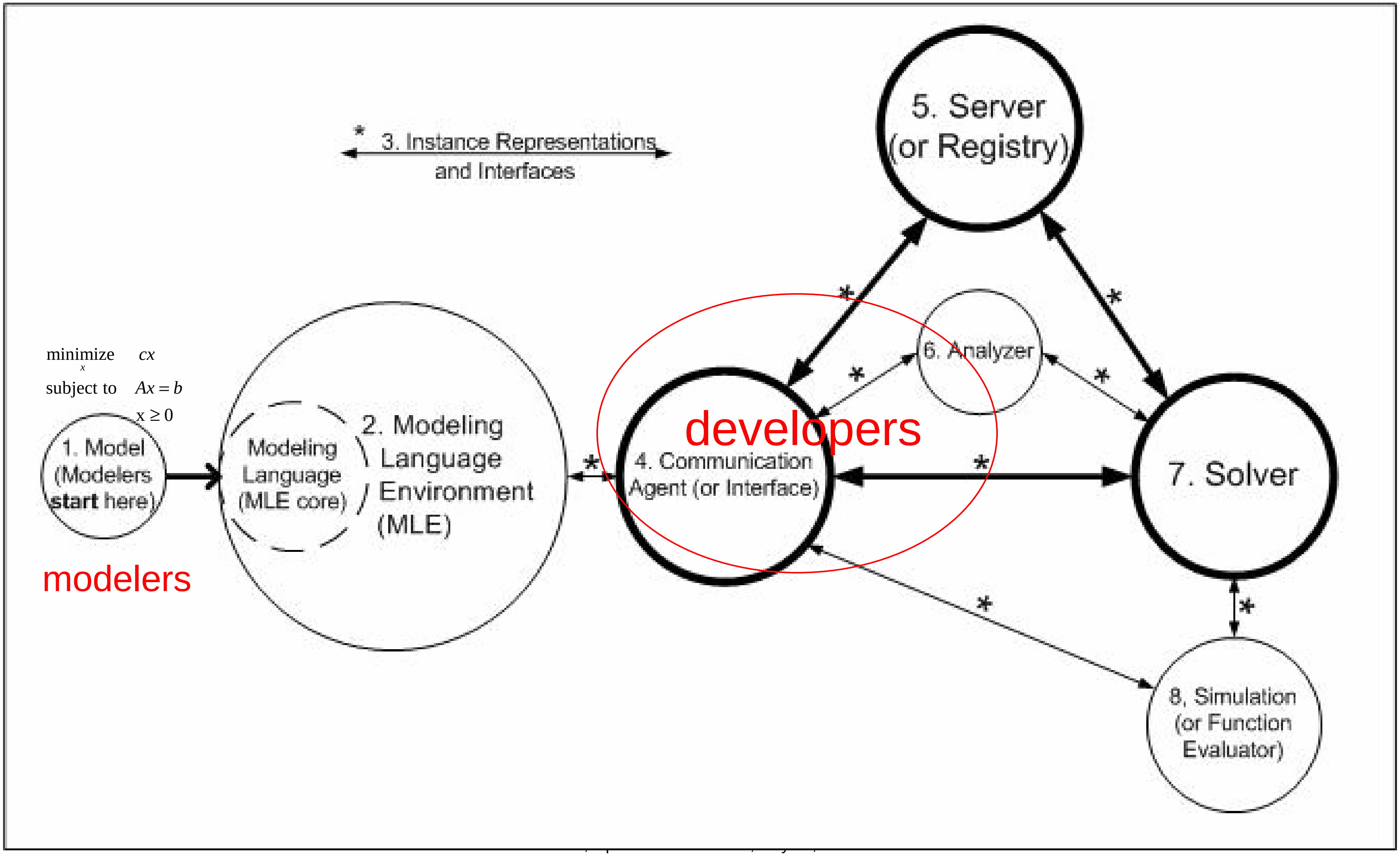
Optimization System Background

What does an optimization system look like?

users



minimize cx
x
subject to Ax = b
x ≥ 0
1. Model (Modelers start here)
modelers
Modeling Language (MLE core)
2. Modeling Language Environment (MLE)
* 3. Instance Representations and Interfaces
developers
4. Communication Agent (or Interface)
5. Server (or Registry)
6. Analyzer
7. Solver
8. Simulation (or Function Evaluator)
*

Optimization System Background

What is the difference between a model and an instance?

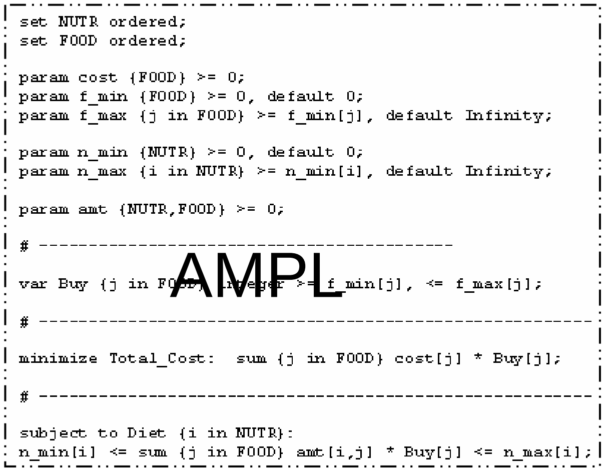
model

high-level, user-friendly
symbolic, general,
concise, understandable

compile

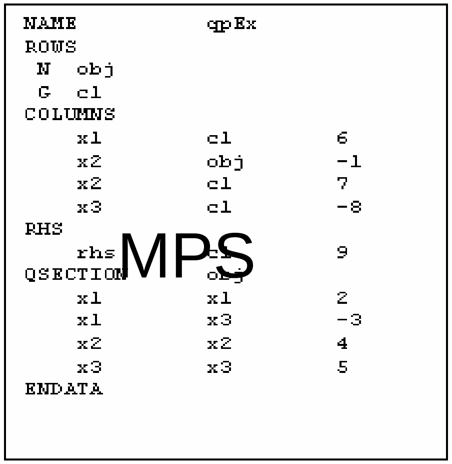
instance

Low-level, computer-friendly
explicit, specific,
redundant, convenient



```
set NUTR ordered;
set FOOD ordered;

param cost {FOOD} >= 0;
param f_min {FOOD} >= 0, default 0;
param f_max {j in FOOD} >= f_min[j], default Infinity;

param n_min {NUTR} >= 0, default 0;
param n_max {i in NUTR} >= n_min[i], default Infinity;

param amt {NUTR,FOOD} >= 0;

# ----------------------------------------

var Buy {j in FOOD} integer >= f_min[j], <= f_max[j];

# -------------------------------------------------------

minimize Total_Cost:  sum {j in FOOD} cost[j] * Buy[j];

# -------------------------------------------------------

subject to Diet {i in NUTR}:
n_min[i] <= sum {j in FOOD} amt[i,j] * Buy[j] <= n_max[i];
```

AMPL

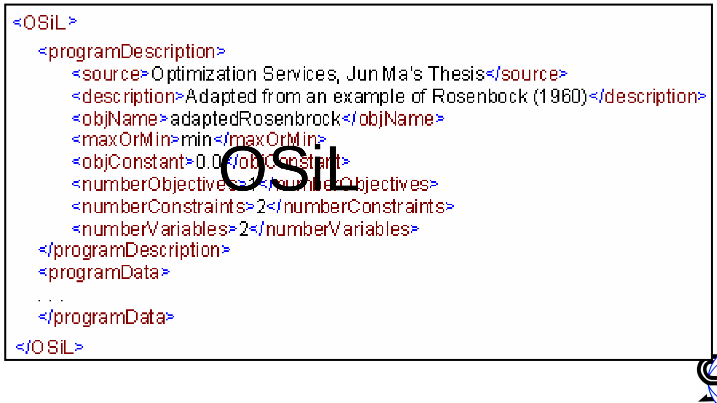


```
NAME           qpEx
ROWS
 N  obj
 G  c1
COLUMNS
    x1         c1         6
    x2         obj        -1
    x2         c1         7
    x3         c1         -8
RHS
    rhs        c1         9
QSECTION       obj
    x1         x1         2
    x1         x3         -3
    x2         x2         4
    x3         x3         5
ENDATA
```

MPS

$$\begin{array}{ll} \underset{x}{\text{minimize}} & cx \\ \text{subject to} & Ax = b \\ & x \geq 0 \end{array}$$

$$\begin{array}{ll} \underset{x}{\text{minimize}} & -x_2 + 1/2(2x_1^2 - 3x_1x_3 + 4x_2^2 + 5x_3^2) \\ \text{subject to} & 6x_1 + 7x_2 - 8x_3 \geq 9 \\ & x_1 \geq 0, x_2 \geq 0, x_3 \geq 0 \end{array}$$

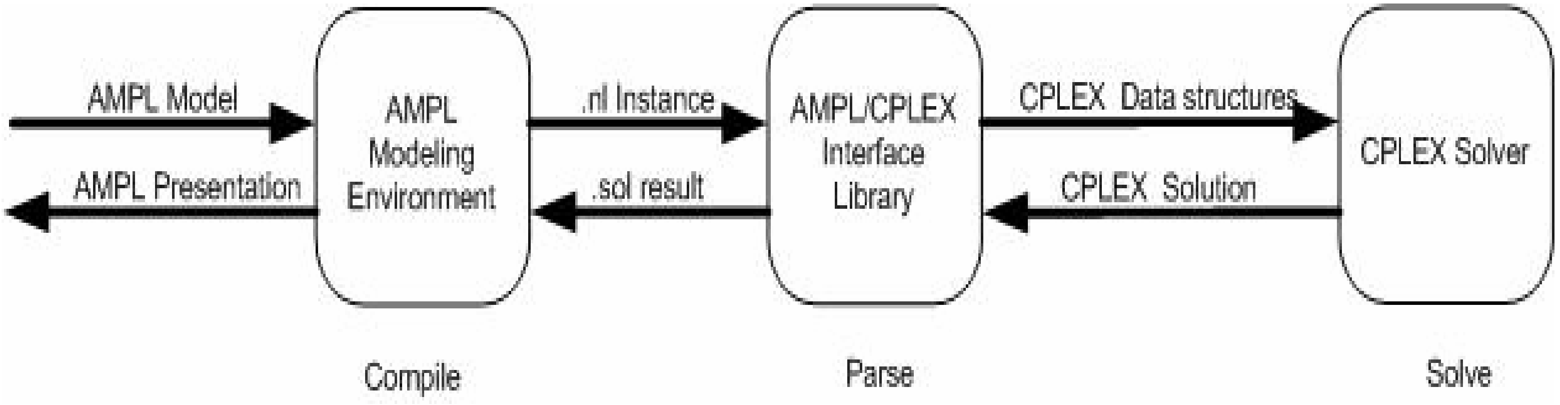


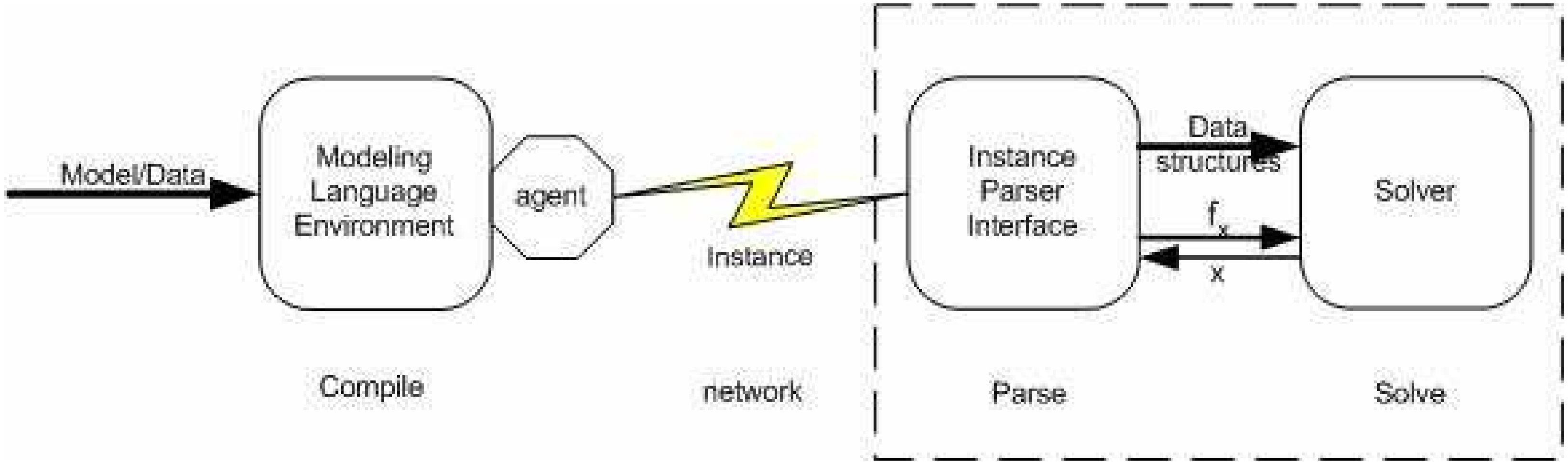
```
<OSiL>
   <programDescription>
      <source>Optimization Services, Jun Ma's Thesis</source>
      <description>Adapted from an example of Rosenbock (1960)</description>
      <objName>adaptedRosenbrock</objName>
      <maxOrMin>min</maxOrMin>
      <objConstant>0.0</objConstant>
      <numberObjectives>1</numberObjectives>
      <numberConstraints>2</numberConstraints>
      <numberVariables>2</numberVariables>
   </programDescription>
   <programData>
   . . .
   </programData>
</OSiL>
```

OSiL

Optimization System Background

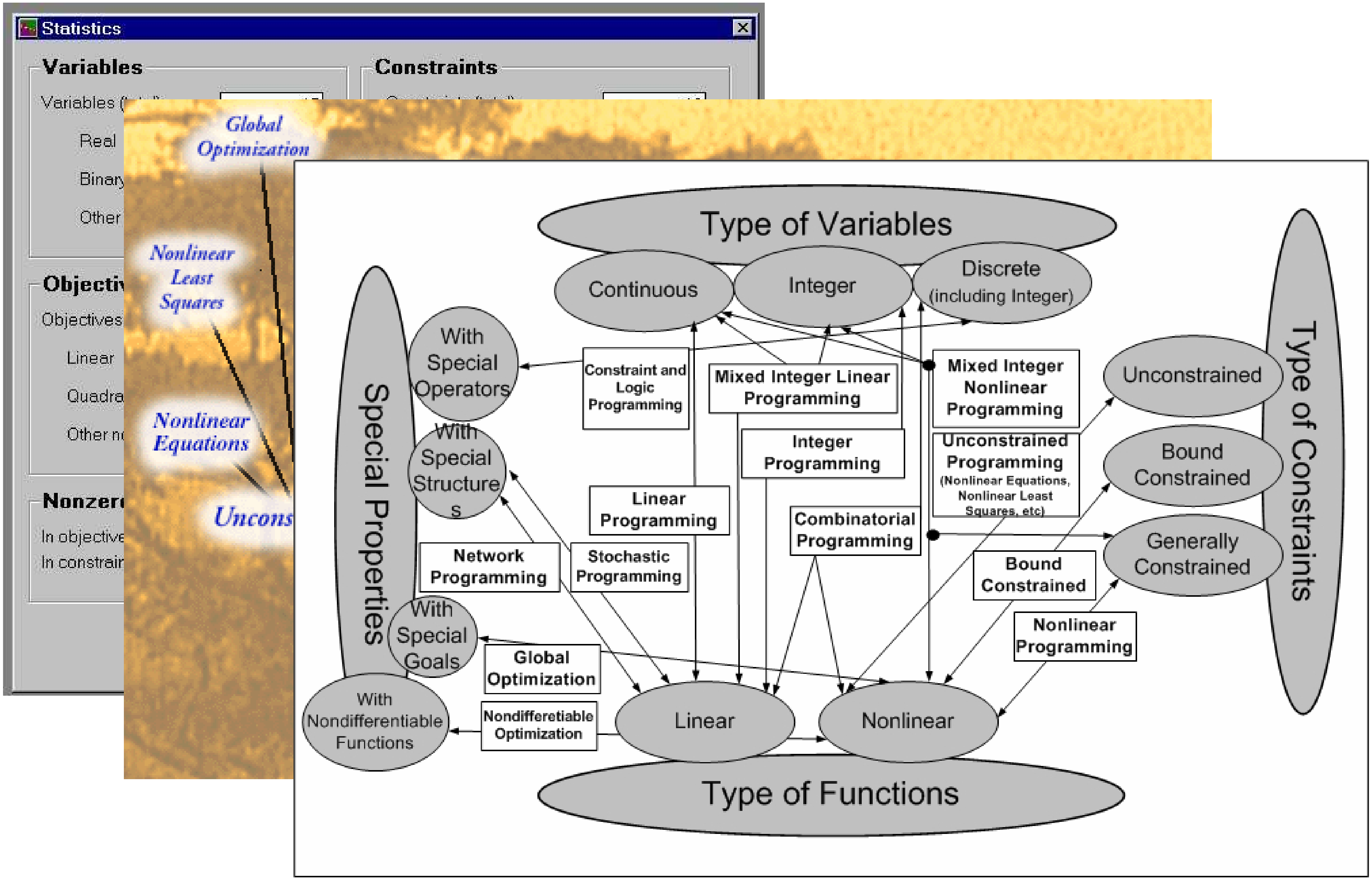
What’s the difference between local interfacing and communication agent





Optimization System Background

Why is analyzer important?



Statistics

Variables

Variables (total)

Real

Binary

Other

Objectiv

Objectives

Linear

Quadra

Other n

Nonzero

In objective

In constrain

Constraints

Constraints (total)

Type of Variables

Continuous

Integer

Discrete (including Integer)

Special Properties

With Special Operators

With Special Structures

With Special Goals

With Nondifferentiable Functions

Constraint and Logic Programming

Mixed Integer Linear Programming

Mixed Integer Nonlinear Programming

Integer Programming

Unconstrained Programming (Nonlinear Equations, Nonlinear Least Squares, etc)

Linear Programming

Combinatorial Programming

Network Programming

Stochastic Programming

Bound Constrained

Nonlinear Programming

Global Optimization

Nondifferetiable Optimization

Type of Constraints

Unconstrained

Bound Constrained

Generally Constrained

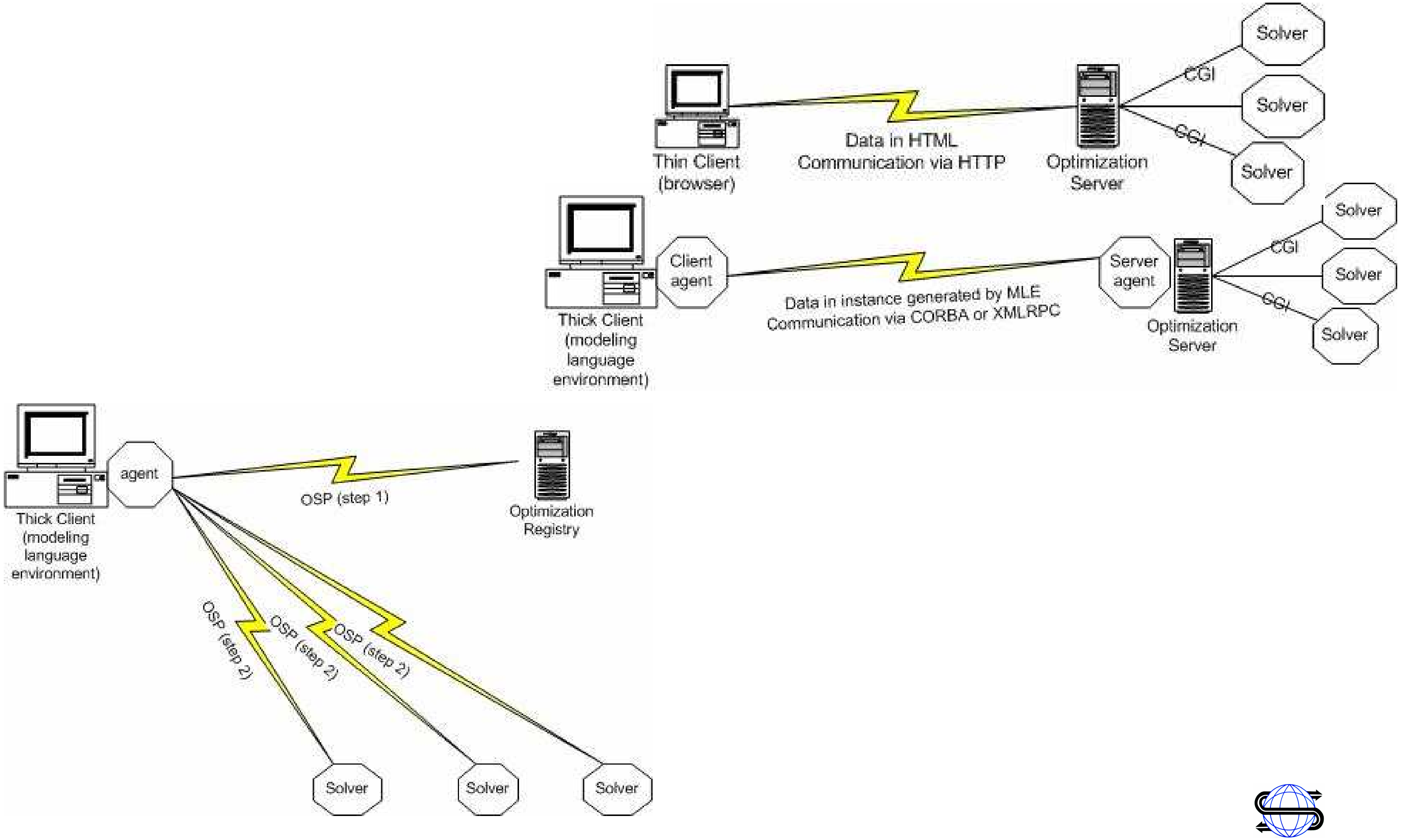
Linear

Nonlinear

Type of Functions

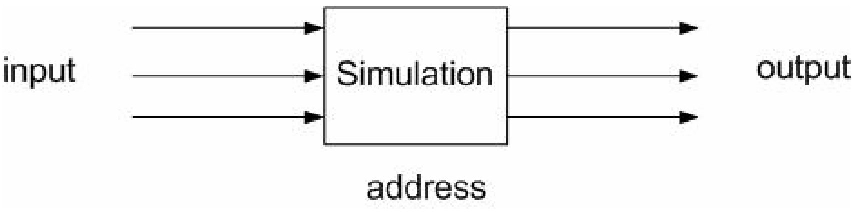
Optimization System Background

What’s the difference between a server and a registry



Optimization System Background

What’s a simulation?



$$\underset{x}{\text{minimize}} \quad mySimulation(x_1, 2, x_2)$$

$$\text{subject to} \quad 2x_1 + 3x_2 \ge 9$$

$$x_1 \ge 0, x_2 \ge 0$$

$$\underset{x}{\text{minimize}} \quad x_1^2 + 2x_2^2$$

$$\text{subject to} \quad 2x_1 + 3x_2 \ge 9$$

$$\mathrm{x}_1 \ge 0, \; x_2 \ge 0$$

$mySimulation\{$

$address = http://somesite.com/mySimulation$

$input:$

a

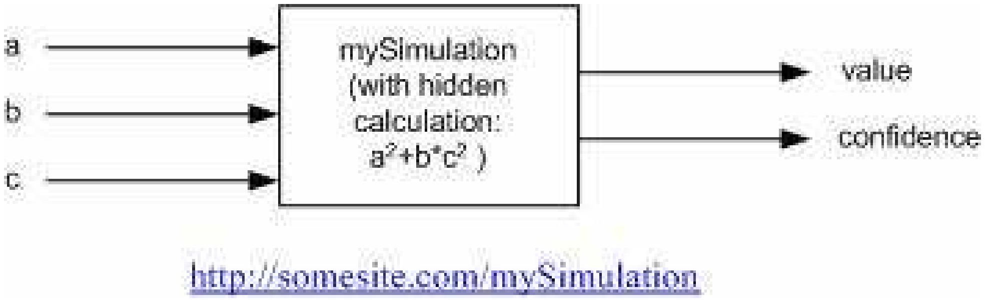
b

c

$output:$

$value + confidence * 0$

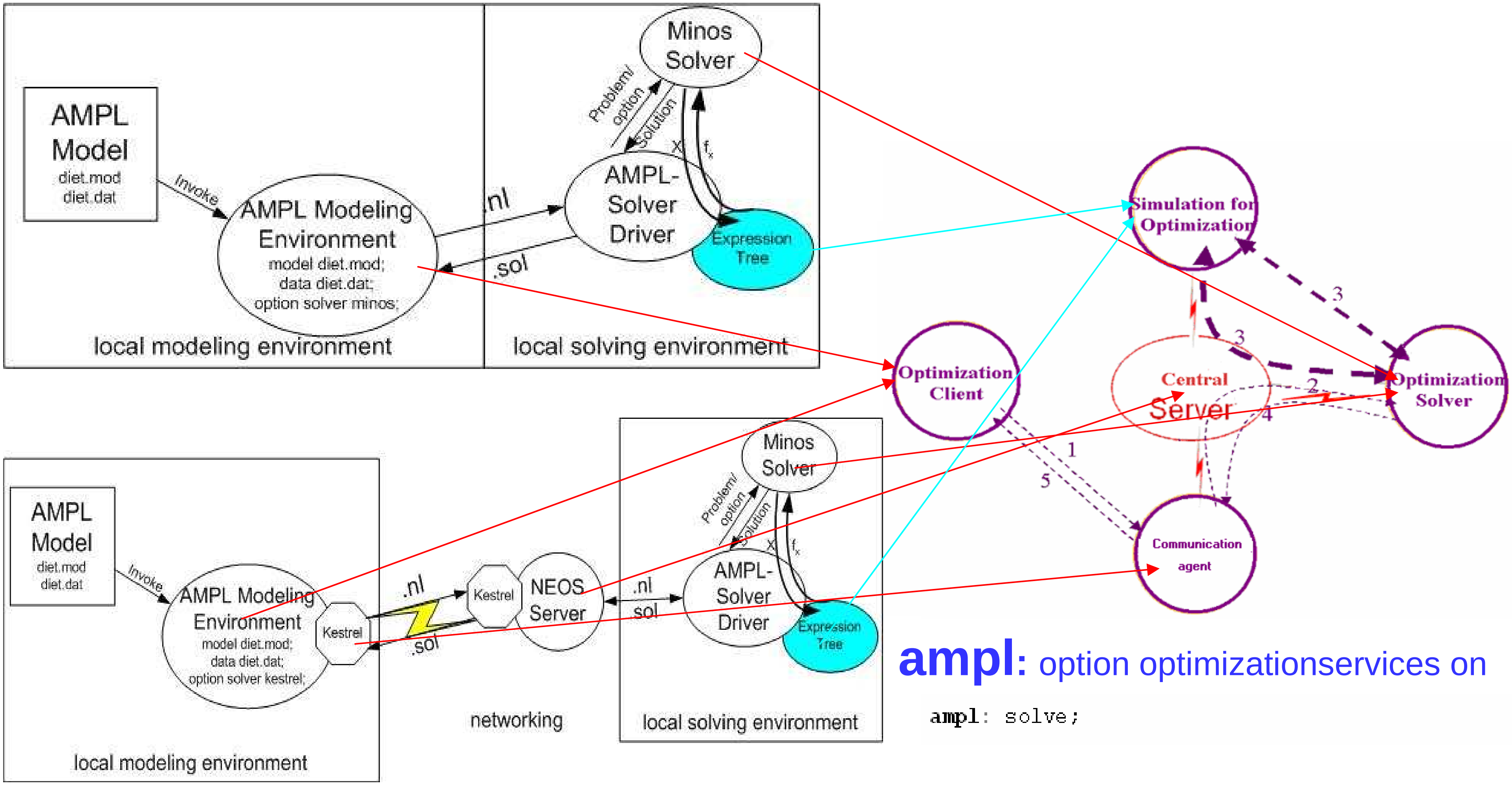
$\}$



http://somesite.com/mySimulation

Optimization System Background

AMPL, NEOS and Kestrel

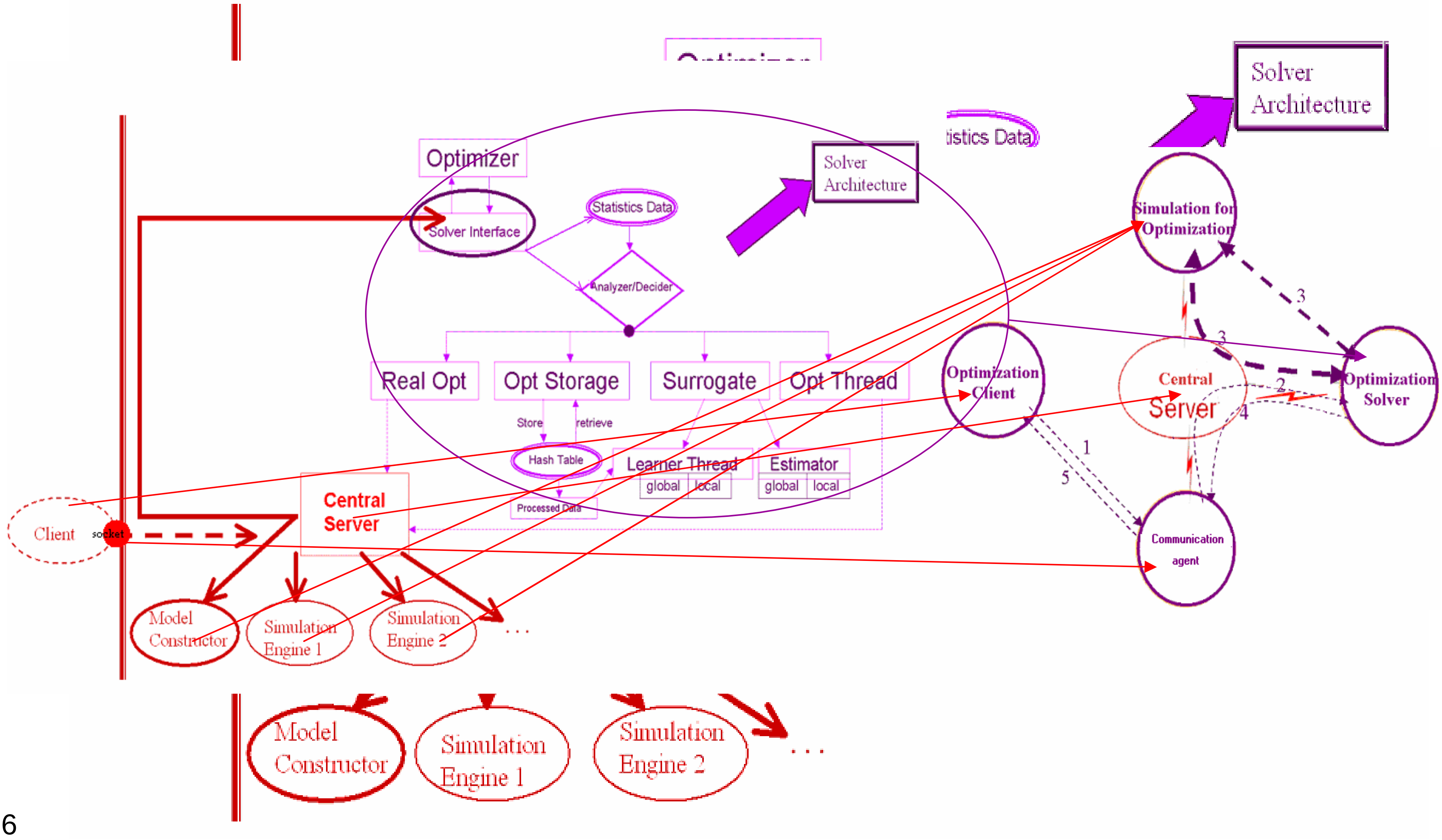


ampl: option optimizationservices on

```
ampl: solve;
```

Optimization System Background

Motorola Optimization System



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Computing and Distributed Background

What we used in our implementation

1. Java, Open Source Libraries, Object-oriented Programming (OS library)

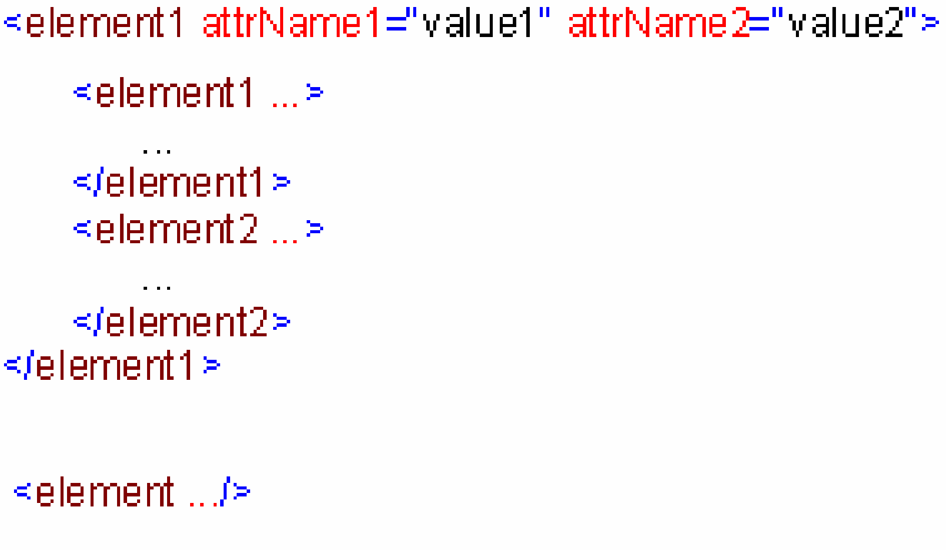
2. Networking Protocols: HTTP, SOAP, OSP (OS server: Tomcat, Axis, OS library)

3. Eclipse IDE for JAVA development

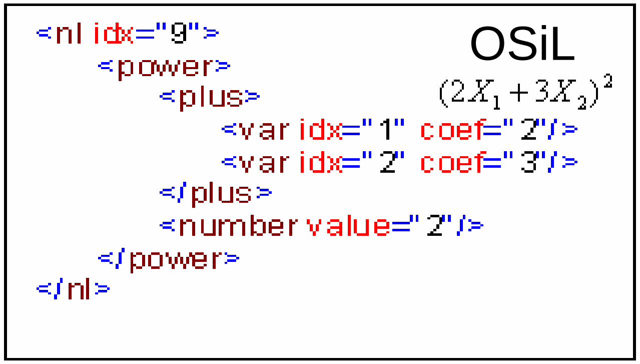
4. XML Spy for XML Schema design

Computing and Distributed Background

XML and XML Dialect (e.g. MathML, OSiL)



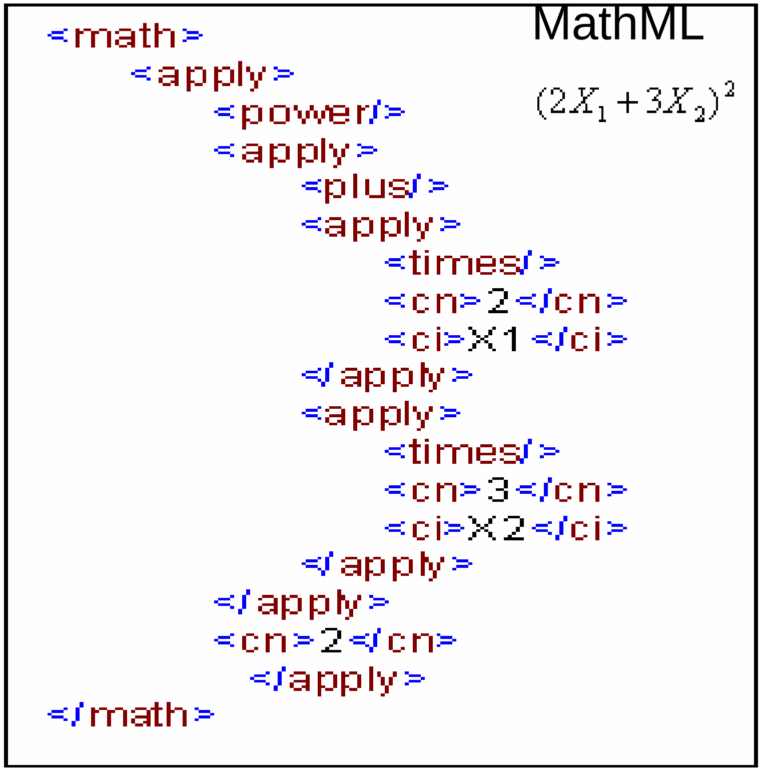
```
<element1 attrName1="value1" attrName2="value2">
    <element1 ...>
        ...
    </element1>
    <element2 ...>
        ...
    </element2>
</element1>


 <element .../>
```



OSiL

$(2X_1 + 3X_2)^2$

```
<nl idx="9">
    <power>
        <plus>
            <var idx="1" coef="2"/>
            <var idx="2" coef="3"/>
        </plus>
        <number value="2"/>
    </power>
</nl>
```



MathML

$(2X_1 + 3X_2)^2$

```
<math>
    <apply>
        <power/>
        <apply>
            <plus/>
            <apply>
                <times/>
                <cn>2</cn>
                <ci>X1</ci>
            </apply>
            <apply>
                <times/>
                <cn>3</cn>
                <ci>X2</ci>
            </apply>
        </apply>
        <cn>2</cn>
      </apply>
</math>
```

Computing and Distributed Background

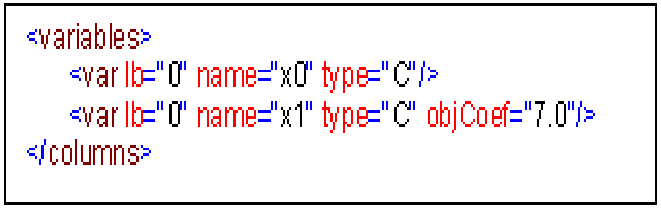
XML Schema

$$\underset{x}{\text{minimize}} \quad 100(x_1 - x_0^2)^2 + (1 - x_0)^2 + 7x_1$$

$$\text{subject to} \quad x_0 + 7x_1 \le 10$$

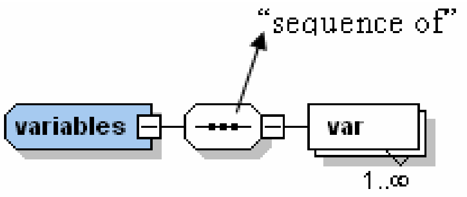
$$\ln(x_0 x_1) + 7x_0 + 5x_1 \le 10$$

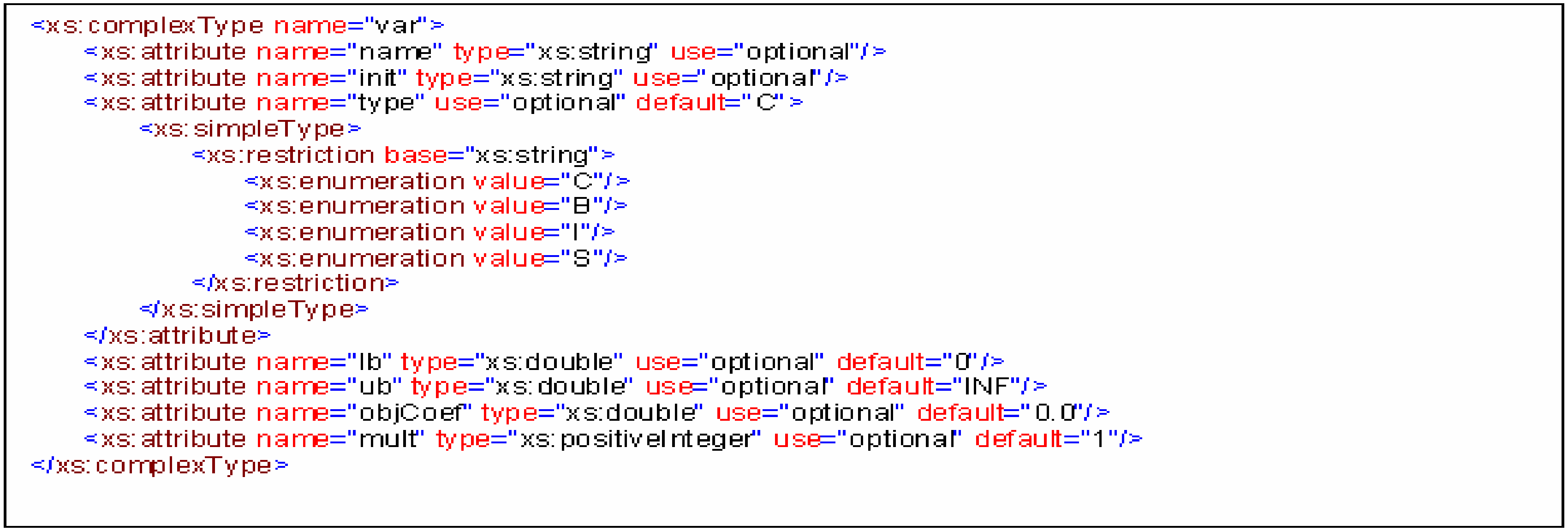
$$x_0, x_1 \ge 0$$



```
<variables>
    <var lb="0" name="x0" type="C"/>
    <var lb="0" name="x1" type="C" objCoef="7.0"/>
</columns>
```

```
<xs:element name="variables">
    <xs:complexType>
        <xs:sequence>
            <xs:element name="var" type="var" minOccurs="1" maxOccurs="unbounded"/>
        </xs:sequence>
    </xs:complexType>
</xs:element>
```





```
<xs:complexType name="var">
    <xs:attribute name="name" type="xs:string" use="optional"/>
    <xs:attribute name="init" type="xs:string" use="optional"/>
    <xs:attribute name="type" use="optional" default="C">
        <xs:simpleType>
            <xs:restriction base="xs:string">
                <xs:enumeration value="C"/>
                <xs:enumeration value="B"/>
                <xs:enumeration value="I"/>
                <xs:enumeration value="S"/>
            </xs:restriction>
        </xs:simpleType>
    </xs:attribute>
    <xs:attribute name="lb" type="xs:double" use="optional" default="0"/>
    <xs:attribute name="ub" type="xs:double" use="optional" default="INF"/>
    <xs:attribute name="objCoef" type="xs:double" use="optional" default="0.0"/>
    <xs:attribute name="mult" type="xs:positiveInteger" use="optional" default="1"/>
</xs:complexType>
```

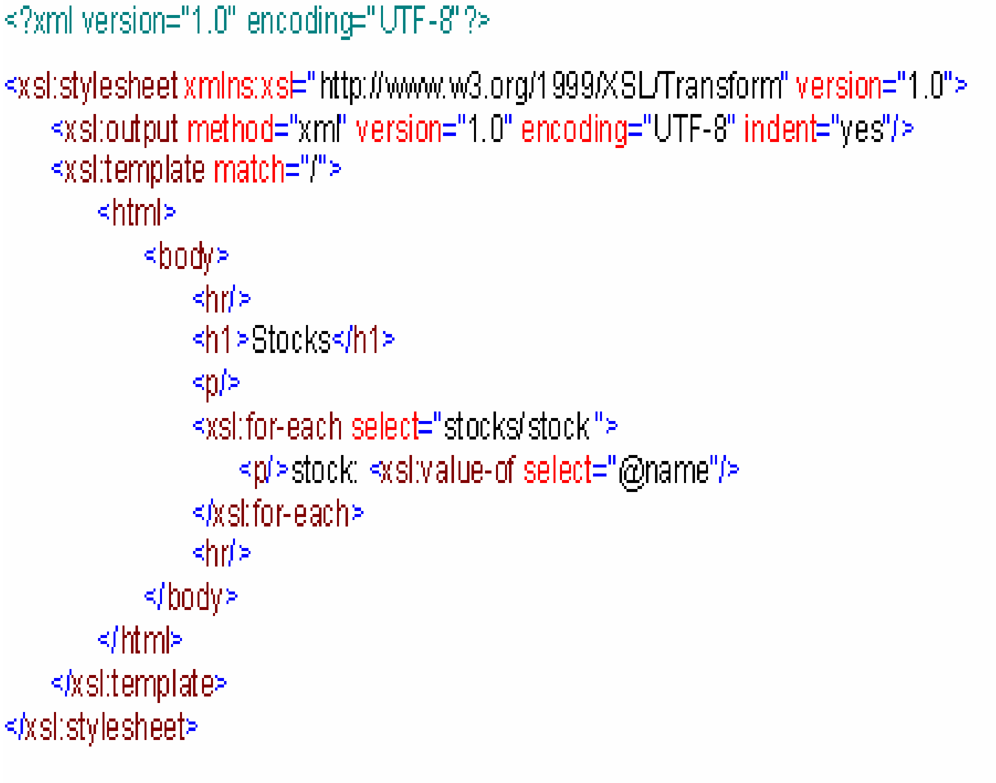
Computing and Distributed Background

Other XML Technologies

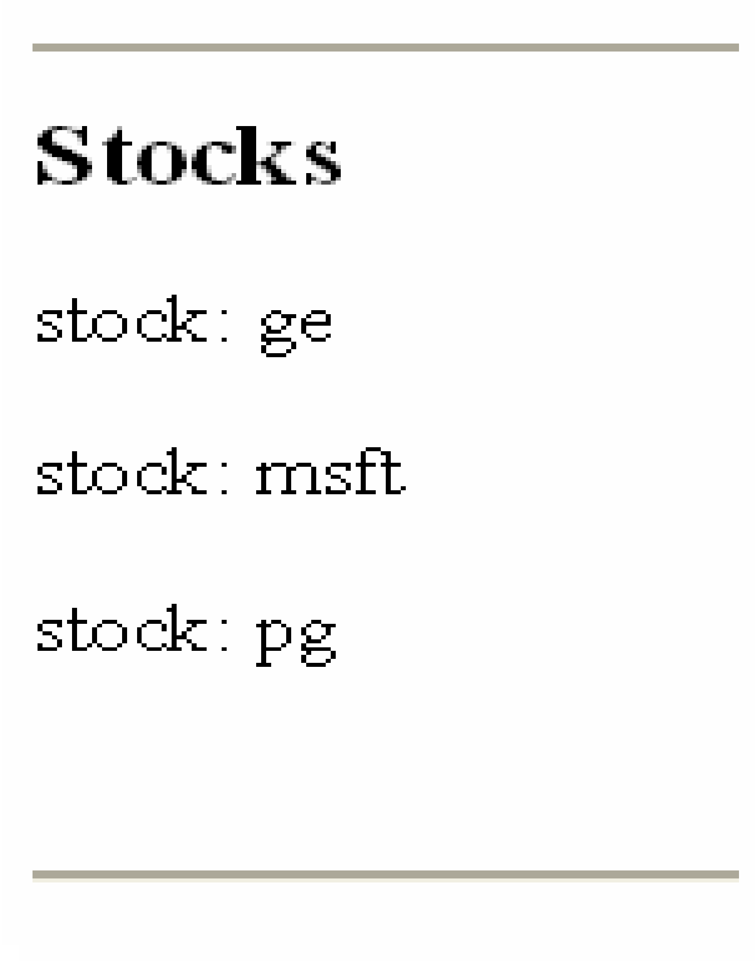
1. **Parsing:** **SAX and DOM models**

2. **Transformation:** **XSL style sheet**

3. **Lookup:** **XPath and XQuery**



```
<?xml version="1.0" encoding="UTF-8"?>

<xsl:stylesheet xmlns:xsl="http://www.w3.org/1999/XSL/Transform" version="1.0">
    <xsl:output method="xml" version="1.0" encoding="UTF-8" indent="yes"/>
    <xsl:template match="/">
        <html>
            <body>
                <hr/>
                <h1>Stocks</h1>
                <p/>
                <xsl:for-each select="stocks/stock">
                    <p/>stock: <xsl:value-of select="@name"/>
                </xsl:for-each>
                <hr/>
            </body>
        </html>
    </xsl:template>
</xsl:stylesheet>
```



Stocks

stock: ge

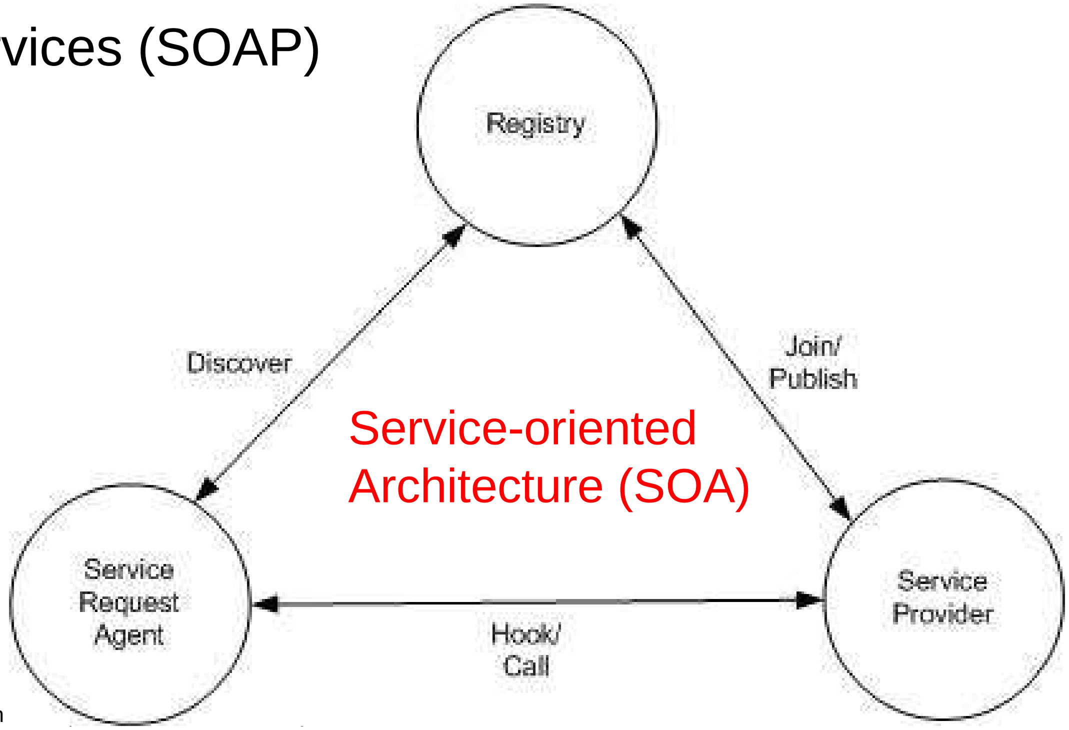
stock: msft

stock: pg

Computing and Distributed Background

Web services

- **Platform and implementation independent** components
- **Described** using a service description language (WSDL)
- **Published** to a registry of services (UDDI, OS Registry)
- **Discovered** through a standard mechanism (UDDI, OS Registry)
- **Invoked** through a declared API (SOAP)
- **Composed** with other services (SOAP)



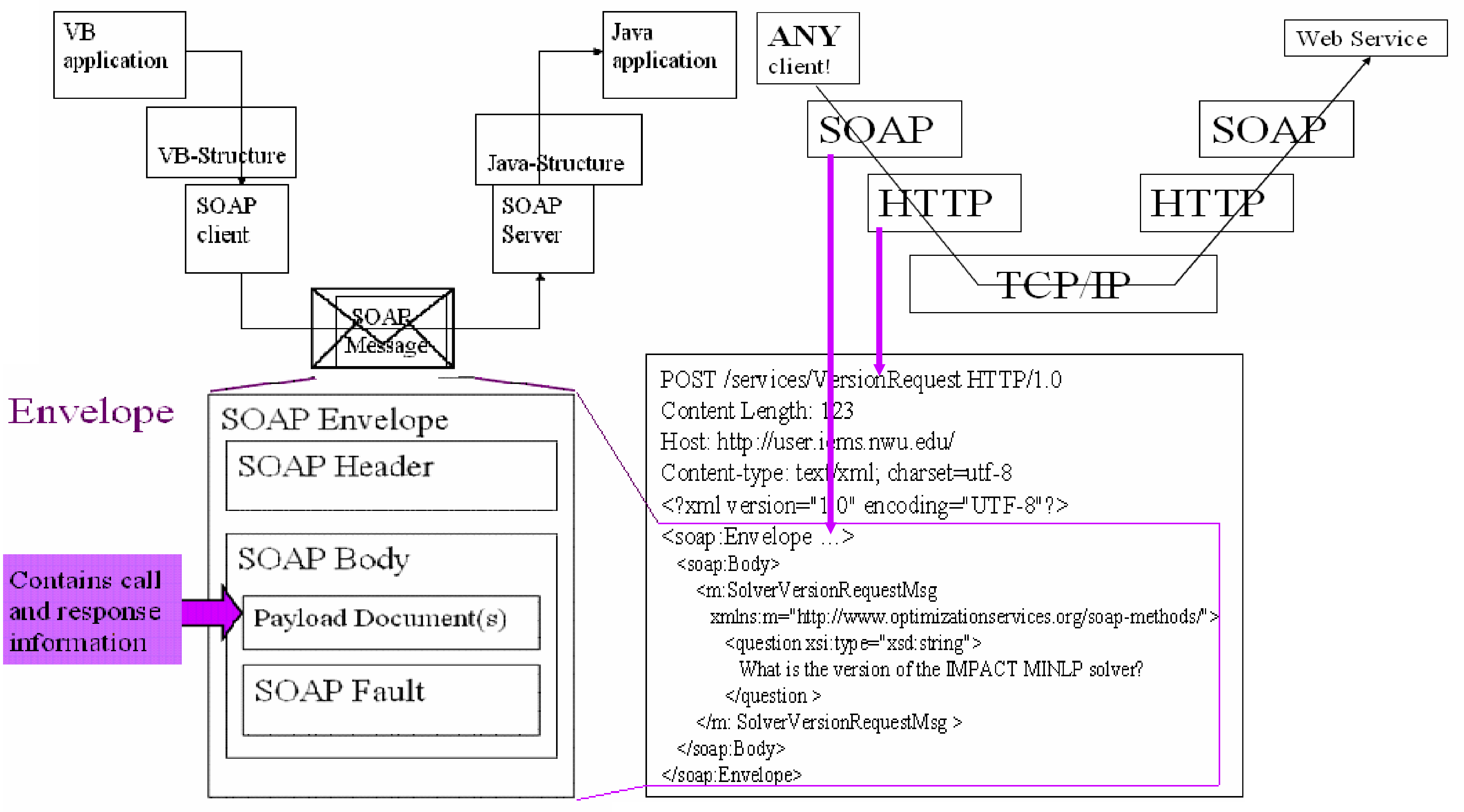
Service-oriented
Architecture (SOA)

Computing and Distributed Background

Web services and SOAP

Architecture View

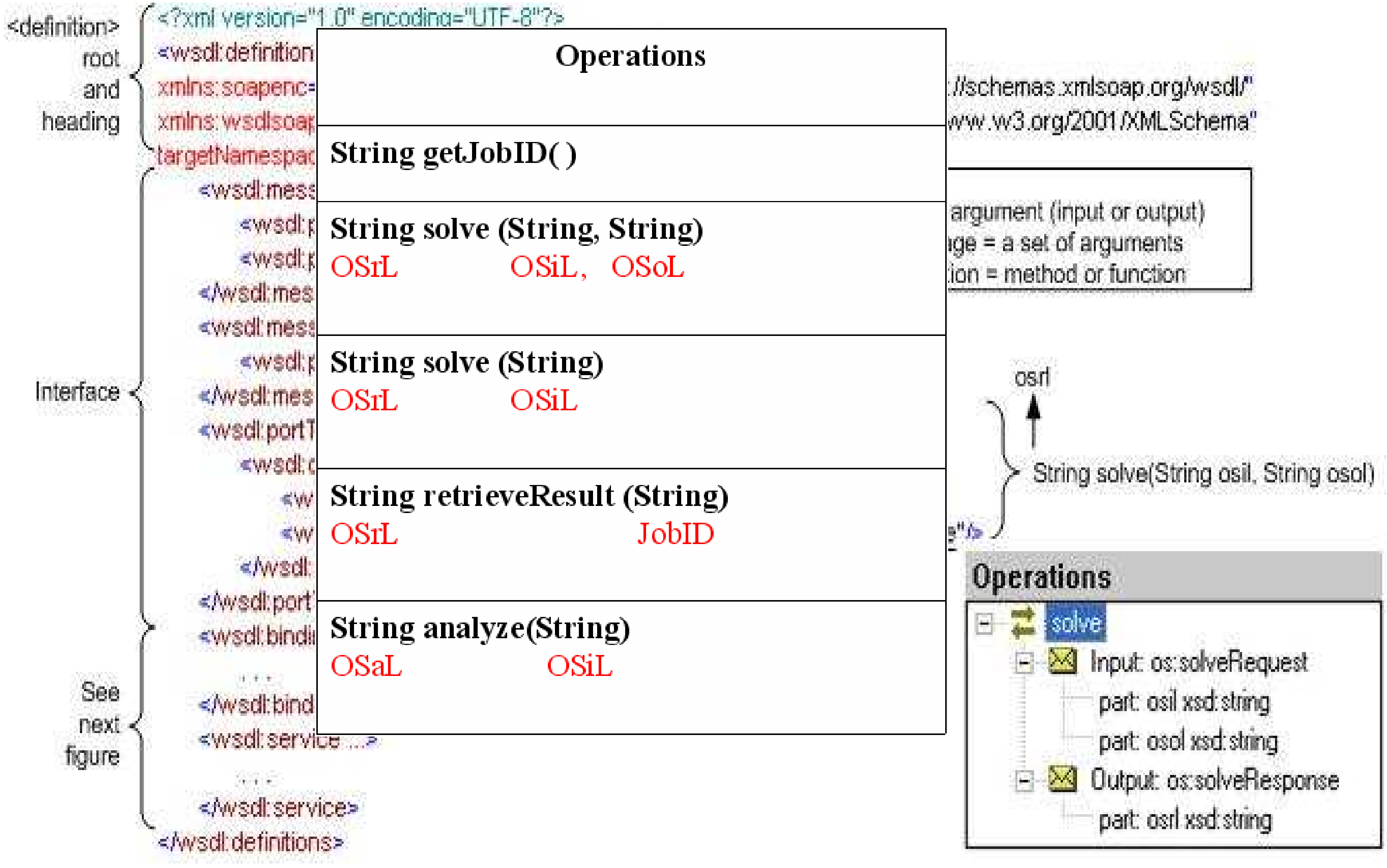
Protocol View



```
POST /services/VersionRequest HTTP/1.0
Content Length: 123
Host: http://user.iems.nwu.edu/
Content-type: text/xml; charset=utf-8
<?xml version="1.0" encoding="UTF-8"?>
<soap:Envelope ...>
  <soap:Body>
    <m:SolverVersionRequestMsg
      xmlns:m="http://www.optimizationservices.org/soap-methods/">
        <question xsi:type="xsd:string">
          What is the version of the IMPACT MINLP solver?
        </question >
    </m: SolverVersionRequestMsg >
  </soap:Body>
</soap:Envelope>
```

Computing and Distributed Background

Web services and WSDL



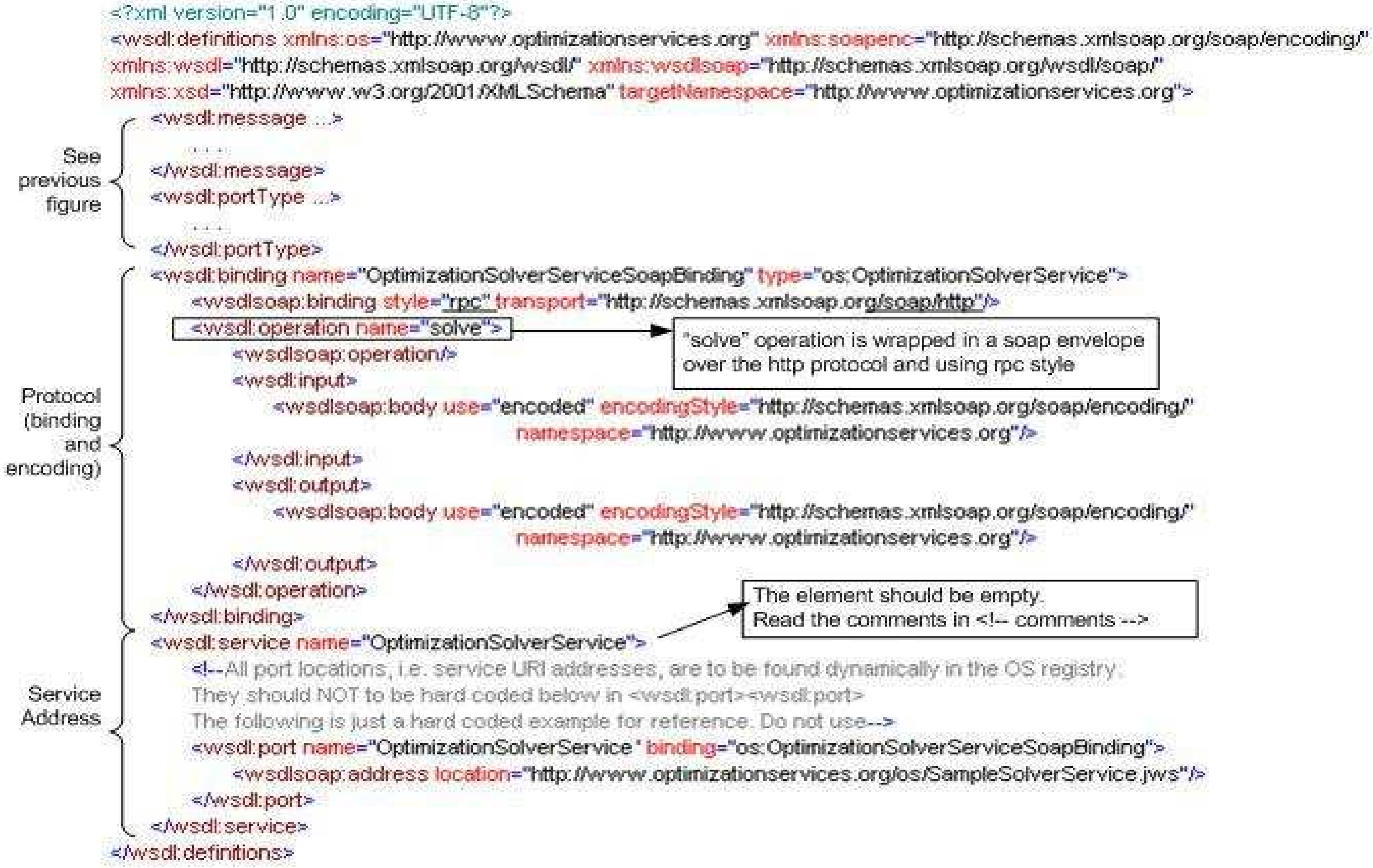
```
<?xml version="1.0" encoding="UTF-8"?>
<wsdl:definition
xmlns:soapenc=                                                        ://schemas.xmlsoap.org/wsdl/"
xmlns:wsdlsoap                                                        ww.w3.org/2001/XMLSchema"
targetNamespac
    <wsdl:mess
        <wsdl:p
        <wsdl:p
    </wsdl:mes
    <wsdl:mess
        <wsdl:p
    </wsdl:mes
    <wsdl:portT
        <wsdl:c
            <w
            <w                                                        e"/>
        </wsdl:
    </wsdl:port
    <wsdl:bindi
       . . .
    </wsdl:bind
    <wsdl:service ...>
       . . .
    </wsdl:service>
</wsdl:definitions>
```

Operations
String getJobID( )
String solve (String, String) OSrL OSiL， OSoL
String solve (String) OSrL OSiL
String retrieveResult (String) OSrL JobID
String analyze(String) OSaL OSiL

```
Operations
⊟ solve
   ⊟ Input: os:solveRequest
        part: osil xsd:string
        part: osol xsd:string
   ⊟ Output: os:solveResponse
        part: osrl xsd:string
```

Computing and Distributed Background

Web services and WSDL



```
<?xml version="1.0" encoding="UTF-8"?>
<wsdl:definitions xmlns:os="http://www.optimizationservices.org" xmlns:soapenc="http://schemas.xmlsoap.org/soap/encoding/"
xmlns:wsdl="http://schemas.xmlsoap.org/wsdl/" xmlns:wsdlsoap="http://schemas.xmlsoap.org/wsdl/soap/"
xmlns:xsd="http://www.w3.org/2001/XMLSchema" targetNamespace="http://www.optimizationservices.org">
    <wsdl:message ...>
        . . . .
    </wsdl:message>
    <wsdl:portType ...>
        . . . .
    </wsdl:portType>
    <wsdl:binding name="OptimizationSolverServiceSoapBinding" type="os:OptimizationSolverService">
        <wsdlsoap:binding style="rpc" transport="http://schemas.xmlsoap.org/soap/http"/>
        <wsdl:operation name="solve">
            <wsdlsoap:operation/>
            <wsdl:input>
                <wsdlsoap:body use="encoded" encodingStyle="http://schemas.xmlsoap.org/soap/encoding/"
                              namespace="http://www.optimizationservices.org"/>
            </wsdl:input>
            <wsdl:output>
                <wsdlsoap:body use="encoded" encodingStyle="http://schemas.xmlsoap.org/soap/encoding/"
                              namespace="http://www.optimizationservices.org"/>
            </wsdl:output>
        </wsdl:operation>
    </wsdl:binding>
    <wsdl:service name="OptimizationSolverService">
        <!--All port locations, i.e. service URI addresses, are to be found dynamically in the OS registry.
        They should NOT to be hard coded below in <wsdl:port><wsdl:port>
        The following is just a hard coded example for reference. Do not use-->
        <wsdl:port name="OptimizationSolverService" binding="os:OptimizationSolverServiceSoapBinding">
            <wsdlsoap:address location="http://www.optimizationservices.org/os/SampleSolverService.jws"/>
        </wsdl:port>
    </wsdl:service>
</wsdl:definitions>
```

"solve" operation is wrapped in a soap envelope over the http protocol and using rpc style

The element should be empty.
Read the comments in <!-- comments -->

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3. Optimization Services and Optimization Services Protocol
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6. **Optimization Services Protocol - Representation**
7. Optimization Services Protocol - Communication
8. Optimization Services Protocol - Registry
9. Optimization Services modeling Language (OSmL)
10. Future and Derived Research

Optimization Services Representation

Who else did this before?

•Many “standards”

•All limited to problem *input*

•Highly fragmented and *no* general format

• Fourer, Lopes, and Martin’s LPFML **(OSIL)**

•Kristjánsson’s OptML

•Bradley’s NaGML

•We are the first in designing

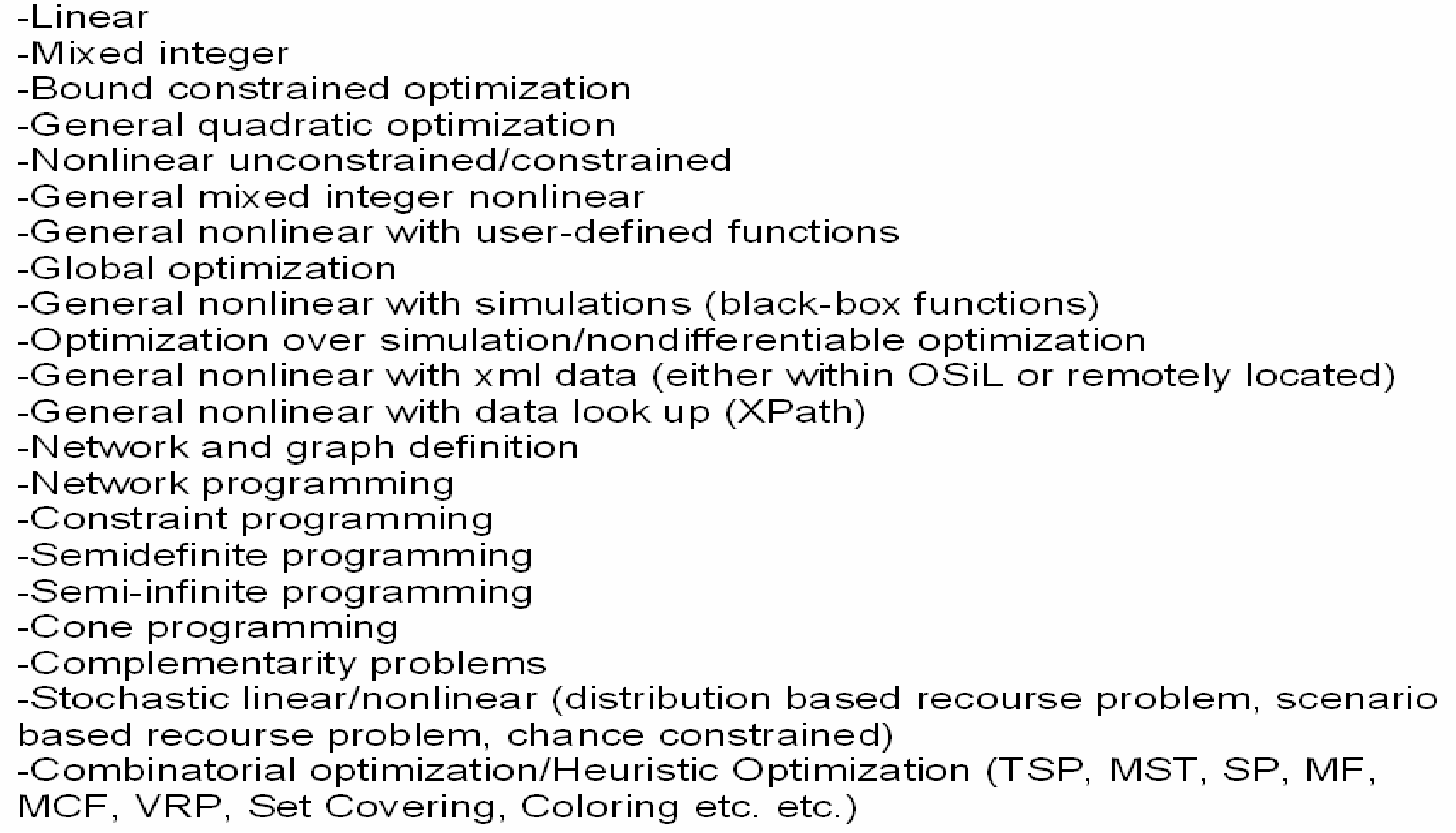
- Systematic representation of major optimization types
- All major instance types (result, analysis, input, query, etc.)
-Web services (SOAP) based communication standards
-Optimization registry
-A universal framework

Optimization Services Representation

Optimization Services general Language (OSgL)

General data structures; Included in other schemas

Optimization Services instance Language (OSiL)



-Linear
-Mixed integer
-Bound constrained optimization
-General quadratic optimization
-Nonlinear unconstrained/constrained
-General mixed integer nonlinear
-General nonlinear with user-defined functions
-Global optimization
-General nonlinear with simulations (black-box functions)
-Optimization over simulation/nondifferentiable optimization
-General nonlinear with xml data (either within OSiL or remotely located)
-General nonlinear with data look up (XPath)
-Network and graph definition
-Network programming
-Constraint programming
-Semidefinite programming
-Semi-infinite programming
-Cone programming
-Complementarity problems
-Stochastic linear/nonlinear (distribution based recourse problem, scenario based recourse problem, chance constrained)
-Combinatorial optimization/Heuristic Optimization (TSP, MST, SP, MF, MCF, VRP, Set Covering, Coloring etc. etc.)

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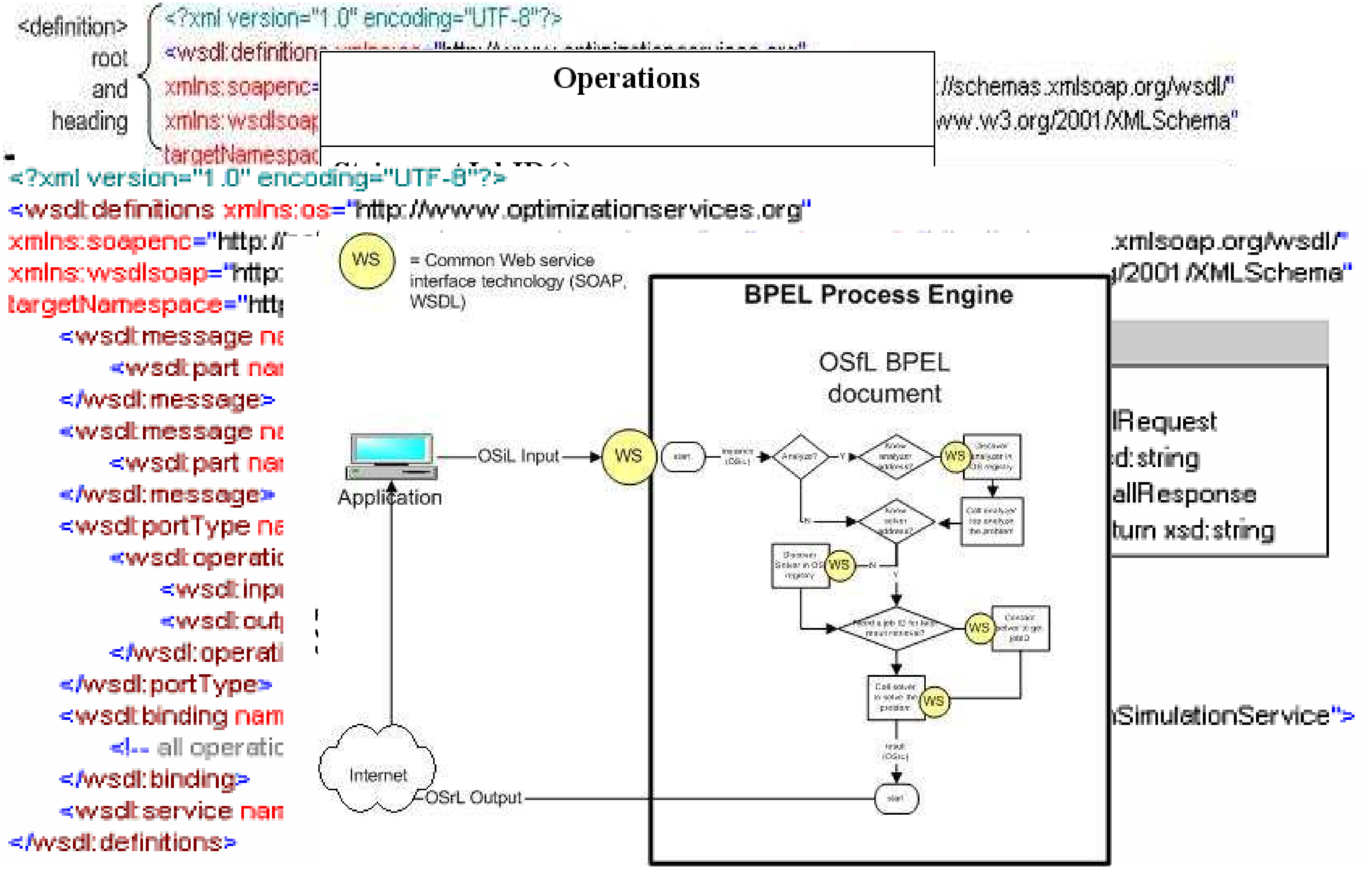
Optimization Services Communication

Optimization Services hookup Language (OShL)

Hookup to solvers, and analyzers



<definition> root and heading

```
<?xml version="1.0" encoding="UTF-8"?>
<wsdl:definition
xmlns:soapenc=
xmlns:wsdlsoap
targetNamespac
://schemas.xmlsoap.org/wsdl/"
ww.w3.org/2001/XMLSchema"
```

Operations

```
<?xml version="1.0" encoding="UTF-8"?>
<wsdl:definitions xmlns:os="http://www.optimizationservices.org"
xmlns:soapenc="http://
xmlns:wsdlsoap="http:
targetNamespace="http
    <wsdl:message na
        <wsdl:part nai
    </wsdl:message>
    <wsdl:message na
        <wsdl:part nai
    </wsdl:message>
    <wsdl:portType na
        <wsdl:operatio
            <wsdl:inp
            <wsdl:out
        </wsdl:operati
    </wsdl:portType>
    <wsdl:binding nam
        <!-- all operatio
    </wsdl:binding>
    <wsdl:service nan
</wsdl:definitions>
.xmlsoap.org/wsdl/"
g/2001/XMLSchema"
lRequest
d:string
allResponse
turn xsd:string
Simulation Service">
```

WS
= Common Web service interface technology (SOAP, WSDL)
BPEL Process Engine
OSfL BPEL document
Application
OSiL Input
WS
start
Analyze?
Y
Know analyzer address?
WS
Discover analyzer in OS registry
Call analyzer the analyze the problem
N
Know solver address?
Discover Solver in OS registry
WS
N
Y
Need a job ID for later result retrieval?
WS
Contact solver to get jobID
Call solver to solve the problem
WS
result (OSrL)
start
Internet
OSrL Output

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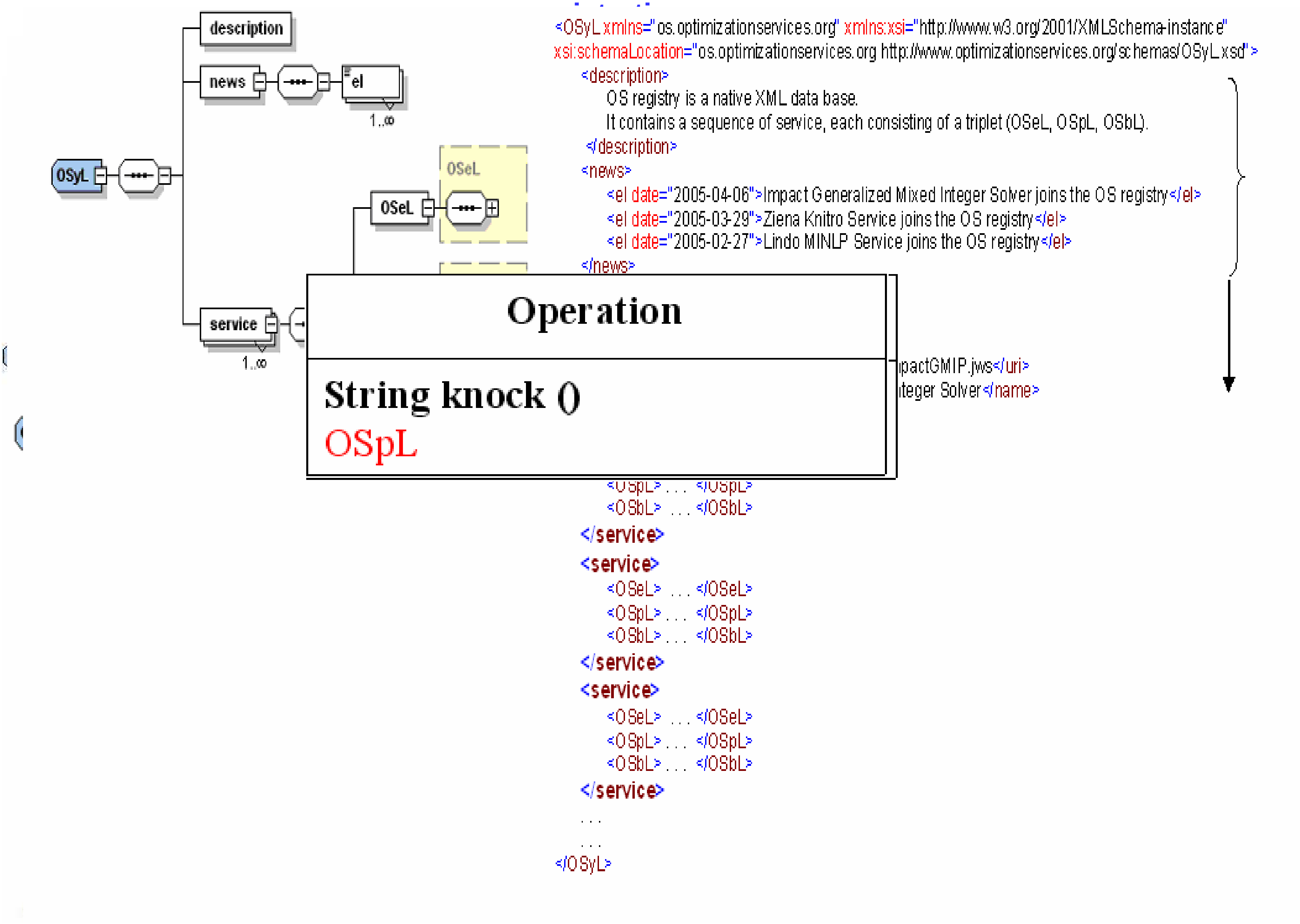
Optimization Services Registry



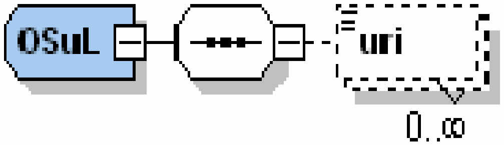
Operation

String knock ()

OSpL

```
<OSyL xmlns="os.optimizationservices.org" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="os.optimizationservices.org http://www.optimizationservices.org/schemas/OSyL.xsd">
    <description>
        OS registry is a native XML data base.
        It contains a sequence of service, each consisting of a triplet (OSeL, OSpL, OSbL).
     </description>
    <news>
        <el date="2005-04-06">Impact Generalized Mixed Integer Solver joins the OS registry</el>
        <el date="2005-03-29">Ziena Knitro Service joins the OS registry</el>
        <el date="2005-02-27">Lindo MINLP Service joins the OS registry</el>
    </news>
                                   pactGMIP.jws</uri>
                                   teger Solver</name>
        <OSpL> . . . </OSpL>
        <OSbL>  . . . </OSbL>
    </service>
    <service>
        <OSeL>  . . . </OSeL>
        <OSpL> . . . </OSpL>
        <OSbL> . . . </OSbL>
    </service>
    <service>
        <OSeL>  . . . </OSeL>
        <OSpL> . . . </OSpL>
        <OSbL> . . . </OSbL>
    </service>
    . . .
    . . .
</OSyL>
```

Optimization Services Registry

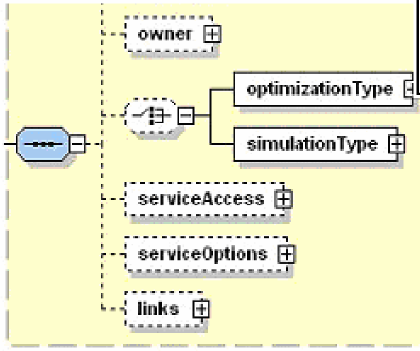


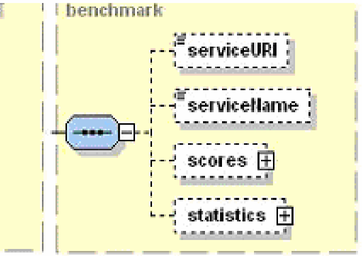
```
<?xml version="1.0" encoding="UTF-8"?>
<OSuL xmlns="os.optimizationservices.org" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="os.optimizationservices.org http://www.optimizationservices.org/schemas/OSuL.xsd">
    <uri>http://www.abc.com/lpsolver.jws</uri>
    <uri match="exact">http://www.edf.net/lpsolverservice.vb</uri>
    <uri match="moreG
    <uri match="appro
    <uri match="guess
</OSuL>
```

Operation

String validate (String)

error Message OSxL





```
            </nonlinear>
        </numberConstraints>
        <numberVariables num="12">
            <continuous num="3"/>
            <integer num="9"/>
            <binary num="0"/>
            <string num="0"/>
        </numberVariables>
    </programDescription>
    <programDataAnalysis> . . . </programDataAnalysis>
</OSaL>
<standard>
    <entity>
        <service>
            <keyWords><key>interior point method</key><key>convex programming</key></keyWords>
        </service>
        <optimizationType>
            <variableType>mixedInteger</variableType>
        </optimizationType>
    </entity>
</standard>
</OSqL>
```

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Optimization Services modeling Language (OSmL)

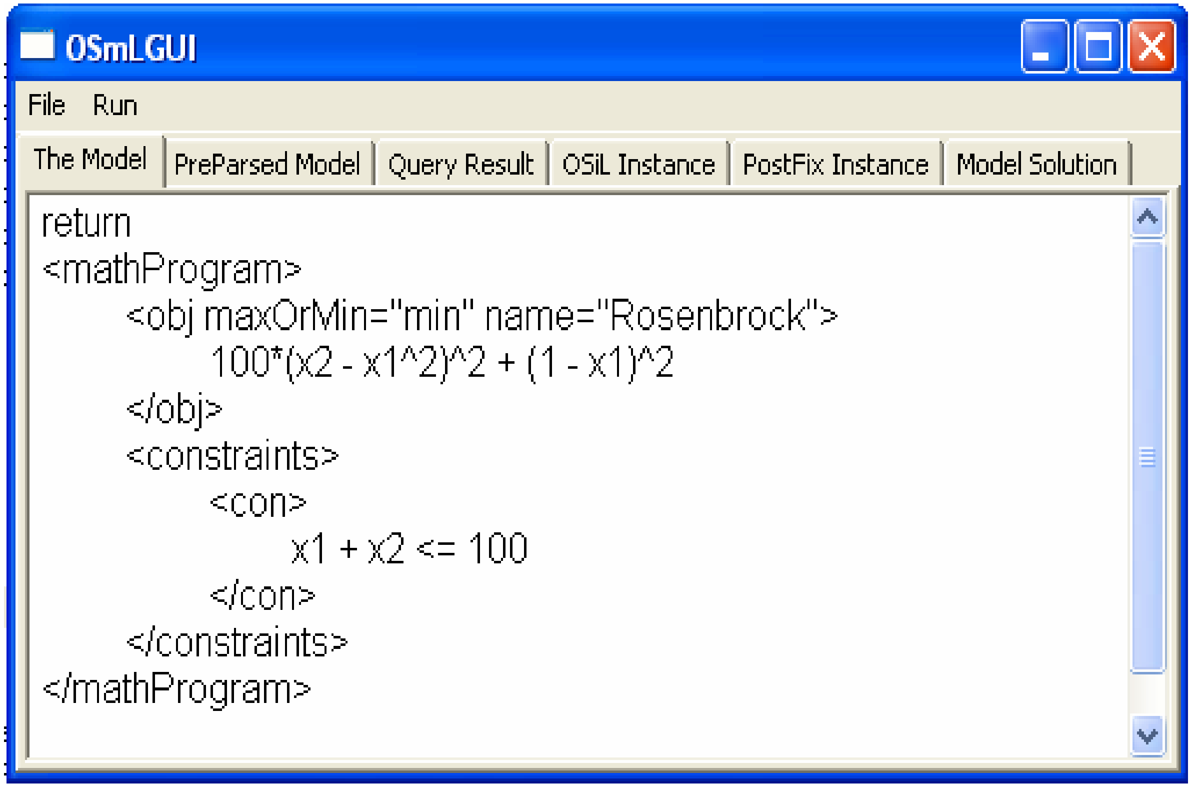
A derived research

Open source and general purpose

Standard based (XQuery input; OSiL output)

Suitable for distributed optimization

XML data is ubiquitous

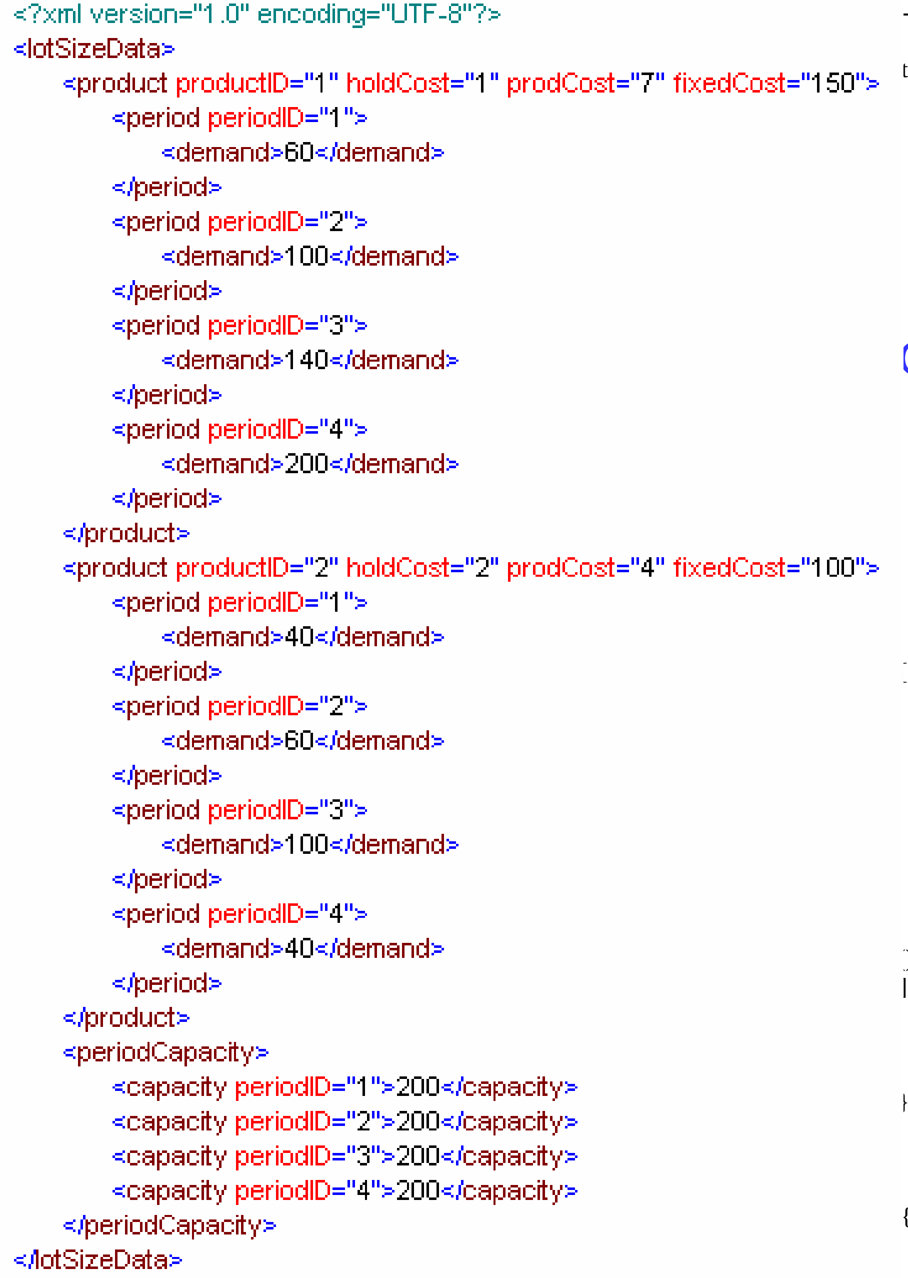


```
return
<mathProgram>
        <obj maxOrMin="min" name="Rosenbrock">
                100*(x2 - x1^2)^2 + (1 - x1)^2
        </obj>
        <constraints>
                <con>
                        x1 + x2 <= 100
                </con>
        </constraints>
</mathProgram>
```

Optimization Services modeling Language

AMPL

```
#set, parameter, and variable constructior
param T;
set PROD;
set LINKS = {PROD, 1..T};
param HC {PROD} ;
param FXC {PROD} ;
param CAP {1..T} ;
param DEM {LINKS};
param PCOST {PROD, 1..T} ;

#VARIABLE DECLARATION
var x  {PROD, 1..T} >= 0;
var I  {PROD, 0..T} >=0;
var y  {PROD, 1..T}binary;

#OBJECTIVE CONSTRUCTION
minimize Total_Cost:
 sum {i in PROD} I[i, 0]  +  sum {i in PR
(PCOST[i, t]*x[i, t] + HC[i]*I[i, t] + FX(

# INITIAL INVENTORY CONSTRAIN
subject to Init_Inv {i in PROD}:
I[i, 0] = 0.0;

# DEMAND CONSTRAINTS
subject to Balance {i in PROD, t in 1..T}
   x[i, t] + I[i, t - 1] - I[i, t] = DEM[i, t];

# FIXED CHARGE CONSTRAINTS
subject to Fixed_Charge {i in PROD, t in
   x[i, t] <= CAP[ t]*y[i, t];

# CAPACITY CONSTRAINTS
subject to Capacity {t in 1..T}:
  sum {i in PROD} x[i, t] <= CAP[ t];
```



```
<?xml version="1.0" encoding="UTF-8"?>
<lotSizeData>
    <product productID="1" holdCost="1" prodCost="7" fixedCost="150">
        <period periodID="1">
            <demand>60</demand>
        </period>
        <period periodID="2">
            <demand>100</demand>
        </period>
        <period periodID="3">
            <demand>140</demand>
        </period>
        <period periodID="4">
            <demand>200</demand>
        </period>
    </product>
    <product productID="2" holdCost="2" prodCost="4" fixedCost="100">
        <period periodID="1">
            <demand>40</demand>
        </period>
        <period periodID="2">
            <demand>60</demand>
        </period>
        <period periodID="3">
            <demand>100</demand>
        </period>
        <period periodID="4">
            <demand>40</demand>
        </period>
    </product>
    <periodCapacity>
        <capacity periodID="1">200</capacity>
        <capacity periodID="2">200</capacity>
        <capacity periodID="3">200</capacity>
        <capacity periodID="4">200</capacity>
    </periodCapacity>
</lotSizeData>
```

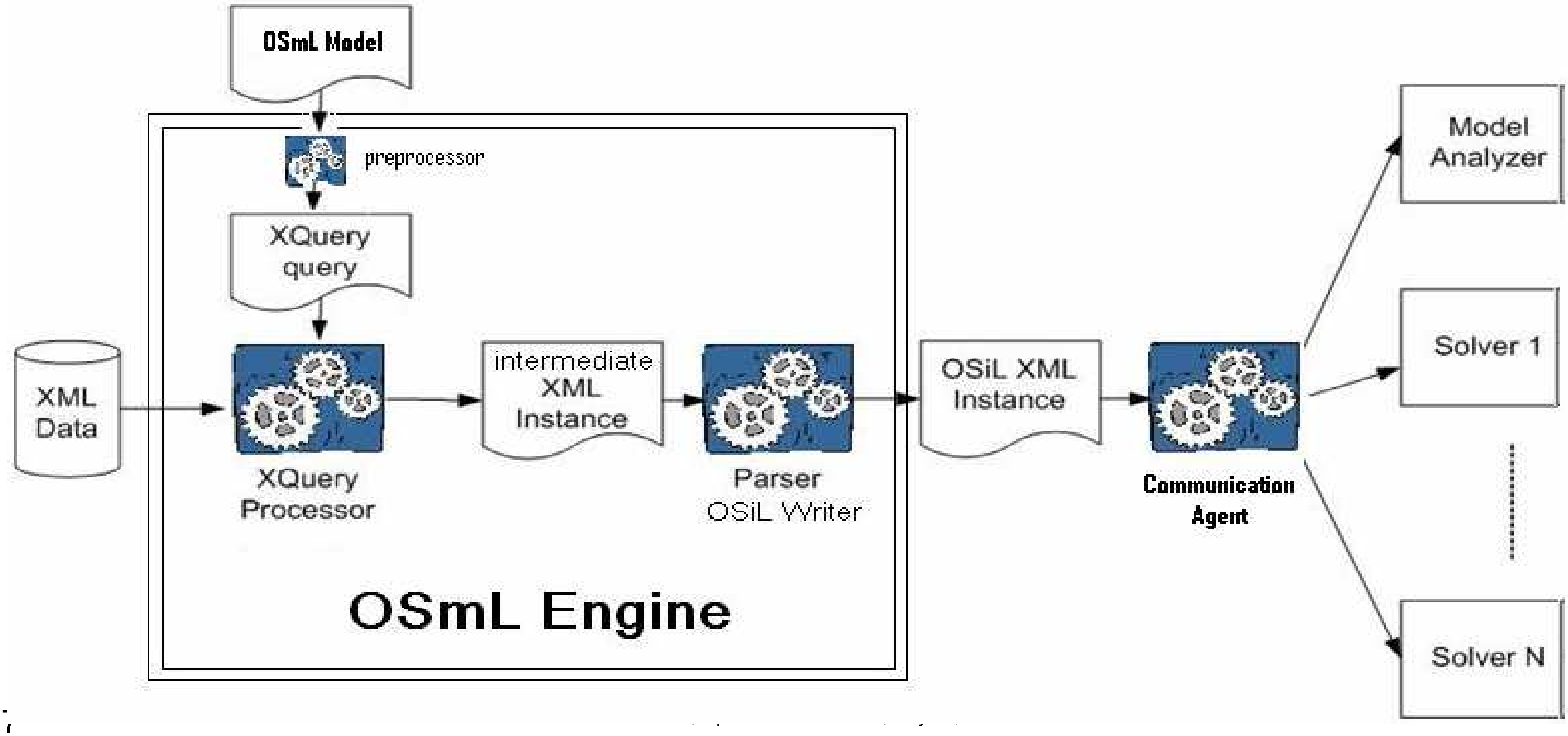
OSmL

```
ty/capacity

$i]}*I[{$i},{$t}])

))    return
| - I[{$i},{$t}] = {$demand} </con>  }

}*Y[{$i},{$t}] <= 0</con> }

{$i},{$t}])<= {$CAP[$t]} </con>}
```

Optimization Services modeling Language

4 ways of combining XML with optimization

1. Use XML to represent the instance of a mathematical program
2. Develop an XML modeling language dialect
3. Enhance modeling languages with XML features such as XPath
4. Use XML technologies to transform XML data into a problem instance



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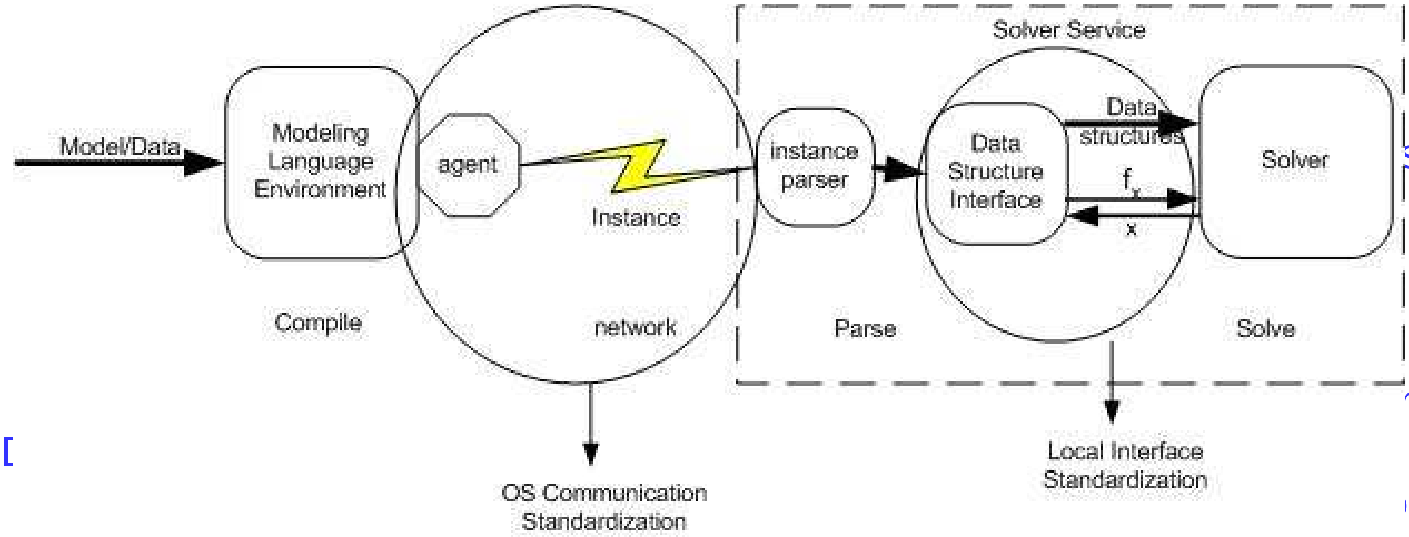
10. **Future and Derived Research**

Future and Derived Research

- The Optimization Services project
- Standardization
- Problem repository building
- OS server software, library enhancement
- Derived research in distributed systems (coordination, scheduling and congestion control)
- Derived research in decentralized systems
  (registration, discovery, analysis, control)
- Derived research in local systems (OSI? OSiI, OSrI, OSoI?)
- Derived research in optimization servers (NEOS)
- Derived research in computational software
  (AMPL, Knitro, Lindo/Lingo, IMPACT, OSmL, MProbe, Dr. AMPL, etc.)
- Derived research in computational algorithm
  Parallel computing



stry.

ntation schemes

- [

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Library developers, registry/server developers, and other auxiliary developers

Computing on demand and “result on demand”

Acknowledgement

- Robert Fourer
- Kipp Martin
- Tom Tirpak and my colleagues at Motorola Advanced Technology Center
- My committee
- Professor Mehrotra’s group
- My wife and my family

http://www.optimizationservices.org (.net)