QoS, Grid Workflows

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Grid Workflow

- Automation of the execution of several Grid Applications (Services)
  - complex Grid Service
- Definition of
  - order of execution of services
  - control structure between services
  - data flow between services
- Models, Languages, and Middleware
Application Areas of Grid Workflow

- Bioinformatics (Taverna & FreeFluo)
- Medical Simulations
- Astronomy (Pegasus)
- Monte Carlo Simulation (Finance)
- Earth Science (Triana)
Script based programming

```perl
#!/usr/bin/perl
# start program A # arg1 arg2 are arguments if any
open (PROGA, "progA arg1 arg2 |") or die "cannot start\n"

$pidofB = <PROGA>; # prog A returns the prog ids,
$pidofE = <PROGA>; # ids, pids of its children, B and E;
waitpid $pidofB; # wait until B ends;
if ($ARGV[0] eq "-display") # do we want to start;
{
    @arg=("C", "arg1", "arg2"); # start program C;
    system(@arg); # wait until C ends;
} else
{
    @arg = ("D", "arg1", "arg2"); # start program D;
    system(@arg) # wait until D ends;
    waitpid $pidofE # wait until E ends;
    @arg = ("F", "arg1", "arg2"); # start program F;
    system (@arg); # wait until F ends;
    @arg = ("G", "arg1", "arg2"); # start program G;
    system(@arg);
}
```

Source: “D. C. Marinescu, 2003”
Disadvantages of Script Programming

- Leads to very complex and confusing scripts
- End user cannot maintain it
- Limited expressivity
- Only block based workflows
- But
  - There is no need for the development of a new grid middleware
  - Performance
  - Several grid workflow projects rest upon script based workflow technology (Pegasus)
### Static WF vs. Static Program Lifecycle

#### Static Workflows
- **Workflow Description Language**
- **User**
  - **Workflow Description**
  - **Verification Engine**
  - **Workflow Database**
  - **Case activation record**
  - **Enactment Engine**

#### Static Programs
- **Programming Language**
- **User**
  - **Computer Program**
  - **Compiler**
  - **Object Code**
  - **Processor Running the Process**

#### Source:
"D. C. Marinescu, 2003"
Dynamic WF vs. Dynamic Program Lifecycle

Component Database

Planning Engine

Dynamic Workflows

Workflow Database

Workflow Description

Verification Engine

Workflow Description

Enactment Engine

Static Workflows

Exception Handling

Workflow Database

Workflow Description

Component Libraries

Static Programs

Automatic Programming

Programming Language

Compiler

Object Code

Processor Running the Process

Dynamic Programs

Program Libraries

Data

Case activation record

Source: “D. C. Marinescu, 2003”
Dynamic WF vs. Dynamic Program Lifecycle

Component Database
Workflow Description Language
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Workflow Database
Static Workflows
Exception Handling
Case activation record

Component Libraries
Automatic Programming
Static Programs
Dynamic Programs
Program Libraries

Source: “D. C. Marinescu, 2003”
Grid Workflow Concepts

Source: "Yu, Buyya 2005"
### Grid Workflow Systems

<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
<th>Prerequisite</th>
<th>Grid Integration</th>
<th>Applications</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAGMaR [120]</td>
<td>University of Wisconsin-Madison, USA, <a href="http://www.cs.wisc.edu/condor/dagmar/">http://www.cs.wisc.edu/condor/dagmar/</a></td>
<td>Condor</td>
<td>Condor which can run on top of Globus Toolkit version 2 (GT2)</td>
<td>Computational-intensive</td>
<td>GPL (General Public License)</td>
</tr>
<tr>
<td>Pegasus [111]</td>
<td>University of Southern California, USA, <a href="http://pegasus.isi.edu">http://pegasus.isi.edu</a></td>
<td>Condor, DAGMaR, Globus RLS</td>
<td>Condor and Globus</td>
<td>Targeted for data-intensive, but supports other types</td>
<td>GTPL (Globus Toolkit Public License)</td>
</tr>
<tr>
<td>Taverna [100]</td>
<td>Collaboration between several European Institutes and industries, <a href="http://taverna.sourceforge.net/">http://taverna.sourceforge.net/</a></td>
<td>Java 1.4+</td>
<td>Service Grids</td>
<td>GNU Lesser General Public License (LGPL)</td>
<td></td>
</tr>
<tr>
<td>GRADS [18]</td>
<td>Collaboration between several American Universities, <a href="http://www.hyperic.com/grads/">http://www.hyperic.com/grads/</a></td>
<td>Globus Toolkit, Autopilot, NWS</td>
<td>Global, Parallel Systems (e.g. MPI)</td>
<td>Computational and communication-intensive applications with MPI components</td>
<td>Not yet available in public</td>
</tr>
<tr>
<td>Gridbus workflow [144]</td>
<td>The University of Melbourne, Australia, <a href="http://www.gridbus.org">http://www.gridbus.org</a></td>
<td>Globus Toolkit</td>
<td>GT2</td>
<td>Computational- and Data-intensive</td>
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<td>Kaseja [76]</td>
<td>Argonne National Laboratory, <a href="http://www.cogkit.org">http://www.cogkit.org</a></td>
<td>Java 1.4</td>
<td>GT2, GT3, Condor, runtime.exe, ssh, WebsDAV</td>
<td>Those required to access Grid middleware</td>
<td>GGPL</td>
</tr>
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</table>

*Source: “Yu, Buyya 2005”*
Grid Workflow Taxonomy

- Workflow Composition Systems
- Workflow QoS Constraints
- Information Retrieval
- Workflow Scheduling
  - Architecture, decision making, planning Scheme
- Scheduling Architecture
  - Centralized, hierarchical, decentralized
- Decision Making
  - Local, global

Source: “Yu, Buyya 2005”
Grid Workflow Projects: Pegasus
PEGASUS – Planning for Execution in Grids
Planning → Scheduling → Executing of complex Grid Workflows
Virtual Organizations (VO)
  – Need Virtual Data (VD)
Expensive data processing
  – Sharing of data products
Abstract workflow
  – Independent of the Grid resources
  – Terms of computation without identifying resources
Executable workflow
  – Workflows are bound to particular resources
Pegasus: Mapping *abstract workflows* into *concrete workflows*
DAGMan guides workflow mapping process
Chimera’s Virtual Data Language

TR preprocess( output b[], input a ) {
    argument = "-a top -T60"; argument = " -i "${input:a}; argument = " -o "${output:b}; }
TR findrange( output b, input a2, input a1, none name="findrange", none p="0.0" ) {
    argument arg = "-a "${none:name} " -T60"; argument = "${input:a2};
    argument = " -o "${output:b}; argument = " -p "${none:p};
...

DV top->preprocess( b=[ @{output:"f.b1":"true"}, @{output:"f.a"} ];
DV left->findrange( b=[@{output:"f.c1":"true"}, a2[@{input:"f.b2":"true"}],
    a1[@{input:"f.b1":"true"}],
    name="left", p="0.5" );
DV right->findrange( b=[@{output:"f.c2":"true"}, a2[@{input:"f.b2":"true"}],
    a1[@{input:"f.b1":"true"}],
    name="right", p="1.0" );
DV bottom->analyze( b[@{output:"f.d"}], a=[ @{input:"f.c1"}, @ ] );

"Transformations"
Application Invocation (parameter, number of input and output files)

"Derivations"
Application Invocation
Logical input and output files

Unique Names

Chimera’s Output- Abstract Workflow

- Chaining of input and output files
- Specified in DAX (DAG XML)

```xml
<job id="ID000004" name="analyze"
    level="1" dv-name="bottom">
  <argument>-a bottom -T60 -i <filename file="f.c1"/>
         <filename file="f.c2"/>
         -o <filename file="f.d"/>
</argument>
  <uses file="f.c1" link="input">
  </uses>
  <uses file="f.c2" link="input">
  </uses>
  <uses file="f.d" link="output">
  </uses>
</job>
...
<child ref="ID000004">
  <parent ref="ID000002"/>
  <parent ref="ID000003"/>
</child>
```
Finding Resources

• **Globus Replica Location Service (RLS)**
  – Use logical file names to query RLS and obtain physical files
  – Set of logical file names → set of physical file locations
  – Register new (intermediate) data products to RLS

• **Transformation Catalog (TC)**
  – Applications
  – Use logical Transformation Names to query TC
  – Logical TR name → physical location of TR

• **Globus Monitoring and Discovery Service (MDS)**
  – to find available resources and their characteristics
    • Load
    • Scheduler queue length
    • Available disc space
    • gridftp for data movement
    • …
Finding Resources

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Make scheduler decisions
Workflow Reduction I

- Avoid costly computation if data is already available
- Reduction of a workflow for already available resources
- Query RLC for input files
- Some components of the abstract workflow do not appear in the concrete workflow
Workflow Reduction II

- Avoid costly computation, if data is already available
- Reduction of a workflow for already available resources
- Query RLC for input files
- Some components of the abstract workflow do not appear in the concrete workflow
Workflow Execution

- Jobs are submitted to Condor-G for execution
- Gondor-G = Condor + Globus Toolkit
  - Queuing service
  - Credential Management
  - Fault Tolerance
  - Authentication (GSI)
  - Scheduling (GRAM, DUROC)
  - File Transfer (GASS, GridFTP)
  - Resource Description (GRIS, GIIS)
Application Examples

• Bioinformatics and Biology
  – BLAST (Basic Local Alignment Search Tool)
    • Comparing gene and protein sequences against others in public databases
    • Optimal local alignments to a query
  – Tomography

• Astronomy
  – Workflows with large number of small jobs
  – Montage
    • grid-capable astronomical mosaicking application
  – Galaxy Morphology
    • investigate the dynamical state of galaxy clusters and to explore galaxy evolution

• Gravitational-Wave Physics
  – Medium and small jobs
  – Evaluation of gravitational waves
  – Large amount of auxillary data needed
Workflow Partitioning

- Partial workflows reflect the original dependencies between the tasks of the abstract workflow
- Assumption: workflow does not contain any cycles
- Recovery

In the diagram:

Pegasus(X) — Pegasus generates the concrete workflow and the submit files for X = Su(X)

DAGMan(Su(X)) — DAGMan executes the concrete workflow for X
Grid Workflow Projects: Triana
Triana

- Graphical Problem Solving Environment (PSE)
- Dragging workflow components onto workspace
- Connecting components
- Originally developed for GEO 600 project
- Component = unit of execution
- Component = java class
  - Identifying name
  - Input and output “ports”
  - A number of optional name/value parameters
  - Single process method
Triana GUI

Predefined Tools

Workspace

Subworkflow

Source: M. Shields, I. Taylor, 2004
...<task>
  <toolname>Sqrt</toolname>
  <package>Math.Functions</package>
  <inportnum>1</inportnum>
  <outportnum>1</outportnum>
  <input>
    <type>triana.types.GraphType</type>
  </input>
  <output>...</output>
  <parameters>
    <param name="popUpDescription">
      <value>Square root of input data</value>
    </param>
    <param name="guiXPos" type="gui">...</param>
  </parameters>
</task>
...

- Data and control flow
- Multiple inputs (mandatory or optionally)
- Synchronous or asynchronous communication
- Internal representation: Directed Cyclic Graph (DCG)
- No explicit control constructs (branch, ...) →
  - are handled by specific components
- BPEL - pluggable language readers and writers
Virtual Triana Overlay

- Dynamic Virtual Organizations
- Dynamic groups and peers to represent distributed resources
- Triana distributed networks
  - Achieved using Grid Application Prototype Interface (GAP Interface) - subset of GAT interface
    - Advertising
    - Discovery
    - Communication
GAP Bindings

- **Jxta**
  - set of protocols for P2P discovery and communication within P2P networks

- **P2PS**
  - advertisement, discovery and virtual communication

- **Web Services**
  - UDDI registry, and the Web Service Invocation Framework (WSIF)

- **OGSA**
Triana & Web Services

- API implementing GAP binding for Web Services
- Discover
  - Via UDDI registry
  - WSDL location
- Invoke
  - Chaining available Web Services
  - Provenance data
- Publish
  - wizard
Workflow QoS
Motivation

Maxillo-facial surgery simulation

Image Loader

Mesh Generation

Cut and Drag

Finite Element Simulation

Run Config

Workflow

Before simulation

After simulation

"Fingberg, 2003"
QoS Workflow

Constraints:
Budget = 100 €
Time = tomorrow 10 a.m.

Medical Imaging (SPECT)
Reconstruction Services
2D → 3D

Medical Imaging Reconstruction Client

QoS workflow

VGE

QoS-aware services

Source: I. Brandic, S. Benkner, G. Engelbrecht, R. Schmidt, 2005
QoS Workflow

Constraints:
- Budget = 100 €
- Time = tomorrow 10 a.m.

Medical Imaging (SPECT) Reconstruction Services
2D → 3D

Medical practitioner

Medical Imaging Reconstruction Client

QoS workflow

S₁ VGE
S₂ VGE
S₃ VGE
... Sn VGE

Source: I. Brandic, S. Benkner, G. Engelbrecht, R. Schmidt, 2005

QoS-aware services
QoS Workflow

Medical practitioner

Medical Imaging Reconstruction Client

QoS Workflow

Medical Imaging (SPECT) Reconstruction Services

QoS-aware Engine

QoS-aware Engine

predefined workflows

Negotiator

SPECT Process

Executor

$\begin{align*}
p &= 100 \, € \\
t &= \text{tomorrow 10 a.m.}
\end{align*}$

$\begin{align*}
p &= 10 \, € \\
t &= 15 \text{ min.}
\end{align*}$

$\begin{align*}
p &= 15 \, € \\
t &= 20 \text{ min.}
\end{align*}$

$S_1$

$S_2$

$S_3$

$\ldots$

$S_n$

QoS-aware services
Automation of VGE invocation

...<sequence name="SPECTSequence">

<invoke name="upload" wsdl="http://..."
   portType="appex" operation="upload"
   inputVariable="..."/>

<invoke name="start" wsdl="http://..."
   portType="appex" operation="start"
   inputVariable="..."/>

<invoke name="download" wsdl="http://..."
   portType="appex" operation="download"
   inputVariable="..." outputVariable="..."/>

</sequence>
...
...<sequence name="SPECTSequence">
...
<invoke name="start" wsdl="..." portType="...
operation="..." inputVariable="...">
  <qos-constraints ReqDesc="..." wsla="...">
    <qos-constraint name="beginTime"
      value="2004-10-18T10:00:00.000+02:00"/>
    <qos-constraint name="endTime"
      value="2004-10-18T11:00:00.000+02:00"/>
    <qos-constraint name="price" value="5.50"/>
  </qos-constraints>

  </invoke>
...
</sequence>
QoS-aware Workflow Lifecycle

- QoS-aware Engine
- Registry
- Negotiation (WSLA)
- Execution (HTTP+SOAP)
- Optional

User

Services (VGE)

QoS Negotiation

QoS Executor

Service Deployer / Generator

XML parser / unparsers

Rewritten Workflow

Requested QoS

Offered QoS
QoS-aware Workflow Lifecycle

Negotiation (WSLA) ————
Execution (HTTP+SOAP) ————
Optional

Registry Services (VGE)
Rewrite workflow
Requested QoS
Guaranteed QoS

User

Service Deployer / Generator
XML parser / unpars

QoS Negotiation
QoS Executer

Rewrite workflow
VGE Workflow – with guaranteed QoS

...<sequence name="SPECTSequence">
  <qos-constraints ReqDesc="...">
    <qos-constraint name="beginTime"
        value="2004-10-18T10:15:00.000+02:00"/>
    <qos-constraint name="endTime"
        value="2004-10-18T10:45:00.000+02:00"/>
    <qos-constraint name="price" value="5.5"/>
  </qos-constraints>
...
  <invoke name="start" wsdl="..." portType="...",
    operation="...", inputVariable="...">
    <qos-constraints ReqDesc="...", wsla="...">
      <qos-constraint name="beginTime"
        value="2004-10-18T10:15:00.000+02:00"/>
      <qos-constraint name="endTime"
        value="2004-10-18T10:45:00.000+02:00"/>
      <qos-constraint name="price" value="5.5"/>
    </qos-constraints>
  </invoke>
...
</sequence>...
Workflow Scheduling

- Workflow Definition: Task₁, Task₂, Task₃
- Each task has 4 candidate Services
- Given:
  - maximum price of the overall workflow (e.g. 23 Euro)
  - maximum time for the workflow execution (e.g. 24 min)
- Which candidate services satisfy the conditions?
- How to select the cheapest and fastest workflow?

Workflow Scheduling

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- Which candidate services satisfy the conditions?
- How to select the cheapest and fastest workflow?

\[ t_{\text{max}} = 24 \text{ min}, \ p_{\text{max}} = 23 \text{ Euro} \]

## Workflow Optimization Techniques

<table>
<thead>
<tr>
<th>Task 1</th>
<th>S11</th>
<th>t11=10</th>
<th>p11=5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S12</td>
<td>t12=12</td>
<td>p12=4</td>
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<tr>
<td></td>
<td>S13</td>
<td>t13=17</td>
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<td>S24</td>
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<td>t31=4</td>
<td>p31=12</td>
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\[ p_{\text{workflow}} \leq 23 \text{ Euro} \]
\[ t_{\text{workflow}} \leq 24 \text{ min} \]
Workflow Optimization Techniques

- NP - Complete
- Analytic
  - Simplex Algorithm
  - Integer Programming
- AI
  - Genetic Algorithms
  - Simulated Annealing

\[ p_{\text{workflow}} \leq 23 \text{ Euro} \]
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\[ p_{\text{workflow}} \leq 23 \text{ Euro} \]
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max: $Z(x, y) = 3x + 5y$

NB1: $2x + y \leq 70$
NB2: $x + y \leq 80$
NB3: $x \leq 40$
NB4: $x \geq 0$
NB5: $y \geq 0$
Simplex Algorithm

max: \( Z(x, y) = 3x + 5y \)

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### Integer Programming

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Simple Additive Weighting

- **Weighting of QoS Parameters**

\[
Q = \{ Q_{ij} ; 1 \leq i \leq n, 1 \leq j \leq 2 \}
\]

\[
V_{ij} = \begin{cases} 
\frac{Q_{j}^{\text{max}} - Q_{ij}^{\text{min}}}{Q_{j}^{\text{max}} - Q_{j}^{\text{min}}} & \text{if } Q_{j}^{\text{max}} - Q_{j}^{\text{min}} \neq 0 \\
1 & \text{if } Q_{j}^{\text{max}} - Q_{j}^{\text{min}} = 0 
\end{cases}
\]

The higher the value, the lower the quality
(e.g. price)

\[
V_{ij} = \begin{cases} 
\frac{Q_{ij}^{\text{min}} - Q_{j}^{\text{min}}}{Q_{ij}^{\text{max}} - Q_{j}^{\text{min}}} & \text{if } Q_{j}^{\text{max}} - Q_{j}^{\text{min}} \neq 0 \\
1 & \text{if } Q_{j}^{\text{max}} - Q_{j}^{\text{min}} = 0 
\end{cases}
\]

The higher the value, the higher the quality
(e.g. availability)

\[
Q_{11} = (10, 12, 17, 8) \\
Q_{12} = (5, 4, 12, 10) \\
Q_{21} = (12, 15, 8, 6) \\
Q_{22} = (7, 9, 15, 10) \\
Q_{31} = (4, 8, 6, 15) \\
Q_{32} = (12, 11, 9, 7)
\]
Simple Additive Weighting

- Weighting of QoS Parameters

\[ Q = \{Q_{ij}; 1 \leq i \leq n, 1 \leq j \leq 2\} \]

\[
V_{ij} = \begin{cases} 
\frac{Q_{ij}^{\text{max}} - Q_{ij}^{\text{min}}}{Q_{j}^{\text{max}} - Q_{j}^{\text{min}}} & \text{if } Q_{j}^{\text{max}} - Q_{j}^{\text{min}} \neq 0 \\
1 & \text{if } Q_{j}^{\text{max}} - Q_{j}^{\text{min}} = 0 
\end{cases}
\]

\[
V_{ij} = \begin{cases} 
\frac{Q_{ij}^{\text{max}} - Q_{ij}^{\text{min}}}{Q_{j}^{\text{max}} - Q_{j}^{\text{min}}} & \text{if } Q_{j}^{\text{max}} - Q_{j}^{\text{min}} \neq 0 \\
1 & \text{if } Q_{j}^{\text{max}} - Q_{j}^{\text{min}} = 0 
\end{cases}
\]

**Task 1**

- Time: \(Q_{11} = (10, 12, 17, 8)\)
- Price: \(Q_{12} = (5, 4, 12, 10)\)

**Task 2**

- Time: \(Q_{21} = (12, 15, 8, 6)\)
- Price: \(Q_{22} = (7, 9, 15, 10)\)

\(\ldots\)

**Task 3**

- Time: \(Q_{31} = (4, 8, 6, 15)\)
- Price: \(Q_{32} = (12, 11, 9, 7)\)

**Sample Values**

- Task 1:
  - Time: \(V_{11} = (0.777; 0.555; 0; 1)\)
  - Price: \(V_{12} = (0.875; 1; 0; 0.25)\)

- Task 2:
  - Time: \(V_{21} = (0.333; 0; 0.777; 1)\)
  - Price: \(V_{22} = (1; 0.75; 0; 0.625)\)

- Task 3:
  - Time: \(V_{31} = (1; 0.636; 0.818; 0)\)
  - Price: \(V_{32} = (0; 0.2; 0.6; 1)\)
Scores

Preferences:

\[ \omega_l = (0.3; 0.7) \quad \text{where} \quad \sum_{j=1}^{2} \omega_j = 1 \]

\[ \text{Score}(x_i) = \sum_{l=1}^{n} \left( \frac{Q_{l}^\text{max} - Q_{l}^\text{min}}{Q_{l}^\text{max} - Q_{l}^\text{min}} \times \omega_l \right) \]

<table>
<thead>
<tr>
<th>Score</th>
<th>(V_{11})</th>
<th>(V_{12})</th>
<th>(V_{x1} \times 0.3)</th>
<th>(V_{x2} \times 0.7)</th>
<th>Score (S_{xy})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(S_{11})</td>
<td>0.777</td>
<td>0.875</td>
<td>0.233</td>
<td>0.613</td>
<td>0.846</td>
</tr>
<tr>
<td>(S_{12})</td>
<td>0.555</td>
<td>1.000</td>
<td>0.167</td>
<td>0.700</td>
<td>0.867</td>
</tr>
<tr>
<td>(S_{13})</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>(S_{14})</td>
<td>1.000</td>
<td>0.250</td>
<td>0.300</td>
<td>0.175</td>
<td>0.475</td>
</tr>
<tr>
<td>(S_{21})</td>
<td>0.333</td>
<td>1.000</td>
<td>0.100</td>
<td>0.700</td>
<td>0.800</td>
</tr>
<tr>
<td>(S_{22})</td>
<td>0.000</td>
<td>0.750</td>
<td>0.000</td>
<td>0.525</td>
<td>0.525</td>
</tr>
<tr>
<td>(S_{23})</td>
<td>0.778</td>
<td>0.000</td>
<td>0.233</td>
<td>0.000</td>
<td>0.233</td>
</tr>
<tr>
<td>(S_{24})</td>
<td>1.000</td>
<td>0.625</td>
<td>0.300</td>
<td>0.438</td>
<td>0.738</td>
</tr>
<tr>
<td>(S_{31})</td>
<td>1.000</td>
<td>0.000</td>
<td>0.300</td>
<td>0.000</td>
<td>0.300</td>
</tr>
<tr>
<td>(S_{32})</td>
<td>0.636</td>
<td>0.200</td>
<td>0.191</td>
<td>0.140</td>
<td>0.331</td>
</tr>
<tr>
<td>(S_{33})</td>
<td>0.818</td>
<td>0.600</td>
<td>0.245</td>
<td>0.420</td>
<td>0.665</td>
</tr>
<tr>
<td>(S_{34})</td>
<td>0.000</td>
<td>1.000</td>
<td>0.000</td>
<td>0.700</td>
<td>0.700</td>
</tr>
</tbody>
</table>
Objective Function and Constraints

\[
\begin{align*}
Sc_{s_{11}} s_{11} & + Sc_{s_{12}} s_{12} + Sc_{s_{13}} s_{13} + ... \\
... & \\
S_{s_{11}} & + S_{s_{12}} + S_{s_{13}} + S_{s_{14}} \\
S_{s_{21}} & + S_{s_{22}} + S_{s_{23}} + S_{s_{24}} = 1 \\
S_{s_{31}} & + S_{s_{32}} + S_{s_{33}} + S_{s_{34}} = 1 \\
5S_{s_{11}} + 4S_{s_{12}} + 12S_{s_{13}} + 10S_{s_{14}} + 7S_{s_{21}} + 9S_{s_{22}} + 15S_{s_{23}} + 10S_{s_{24}} + 12S_{s_{31}} + 11S_{s_{32}} + 9S_{s_{33}} + 7S_{s_{34}} & \leq 23 \\
10S_{s_{11}} + 12S_{s_{12}} + 17S_{s_{13}} + 8S_{s_{14}} + 12S_{s_{21}} + 15S_{s_{22}} + 8S_{s_{23}} + 6S_{s_{24}} + 4S_{s_{31}} + 8S_{s_{32}} + 6S_{s_{33}} + 15S_{s_{34}} & \leq 24 \\
S_{s_{11}}, S_{s_{12}}, S_{s_{13}}, S_{s_{14}}, S_{s_{21}}, S_{s_{22}}, S_{s_{23}}, S_{s_{24}}, S_{s_{31}}, S_{s_{32}}, S_{s_{33}}, S_{s_{34}} & \in N
\end{align*}
\]

- Equation system may be solved using a solver package (e.g. lp_solve)
Results

<table>
<thead>
<tr>
<th>Task 1</th>
<th>Service 11</th>
<th>t_{11} = 10</th>
<th>p_{11} = 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 2</td>
<td>Service 12</td>
<td>t_{12} = 12</td>
<td>p_{12} = 4</td>
</tr>
<tr>
<td>Task 2</td>
<td>Service 13</td>
<td>t_{13} = 17</td>
<td>p_{13} = 12</td>
</tr>
<tr>
<td>Task 2</td>
<td>Service 14</td>
<td>t_{14} = 8</td>
<td>p_{14} = 10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task 2</th>
<th>Service 21</th>
<th>t_{21} = 12</th>
<th>p_{21} = 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 2</td>
<td>Service 22</td>
<td>t_{22} = 15</td>
<td>p_{22} = 9</td>
</tr>
<tr>
<td>Task 3</td>
<td>Service 23</td>
<td>t_{23} = 8</td>
<td>p_{23} = 15</td>
</tr>
<tr>
<td>Task 3</td>
<td>Service 24</td>
<td>t_{24} = 6</td>
<td>p_{24} = 10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task 3</th>
<th>Service 31</th>
<th>t_{31} = 4</th>
<th>p_{31} = 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 3</td>
<td>Service 32</td>
<td>t_{32} = 8</td>
<td>p_{32} = 11</td>
</tr>
<tr>
<td>Task 3</td>
<td>Service 33</td>
<td>t_{33} = 6</td>
<td>p_{33} = 9</td>
</tr>
<tr>
<td>Task 3</td>
<td>Service 34</td>
<td>t_{34} = 15</td>
<td>p_{34} = 7</td>
</tr>
</tbody>
</table>

Time: $12 + 6 + 6 = 24 \leq 24$
Price: $4 + 10 + 9 = 23 \leq 23$
IP Characteristics

• Suitable for
  – Simple workflows
  – Linear constraints and objective functions
  – Small search spaces

• Not suitable for
  – complex workflows
  – large search spaces
  – Non-linear constraints, objective functions
IP Characteristics

• Suitable for
  – Simple workflows
  – Linear constraints and objective functions
  – Small search spaces

• Not suitable for
  – complex workflows
  – large search spaces
  – Non-linear constraints, objective functions
AI Methods

• Genetic Algorithms (GA)
  – idea of natural selection and genetic
  – Charles Darwin’s idea of survival of the fittest
  – Crossover, Mutation
  – Workflow: Select best offers

• Simulated Annealing (SA)
  – metal cools and freezes into a minimum energy crystalline structure
  – Non-linear problem
  – Temperatur
Location Affinity - Motivation

QoS specification: time, price
maxTime = 5 h
price = 20 €
Motivation

QoS specification:
- time, price
- $\text{maxTime} = 5 \, \text{h}$
- price $= 20 \, \text{€}$

Legal and security aspects:
- "Location affinity"

CT image reconstruction

Quasi-real time neurosurgery support

Maxillo facial surgery simulation

MFSS Process diagram

Grid-enabled Medical Simulation Services
QoWL Code Example

```xml
<qowl-element name="activityName" portType="..." wsdl="..." ...>
 ...
 <qos-constraints reqDescVar="..." ...>
   <qos-constraint name="beginTime" value="..." weight="..." />
   <qos-constraint name="endTime" value="..." weight="..." />
   <qos-constraint name="price" value="..." weight="..." />
   <qos-constraint name="geographicAffinity" value="..." />
   <qos-constraint name="gridSiteAffinity" value="..." />
 ...
 </qos-constraints>
</qowl-element>
```

any QoWL element

QoS extension of a BPEL element
Types of Location Affinity

- **Grid site** - `gridSiteAffinity`
  - Security, law, performance reasons

- **Organisation** - `organisationAffinity`
  - Hide business information from competitors
  - Sensitive business data

- **Geographical region** - `geographicAffinity`
  - Legal requirements
  - Electronic transfer of medical data
  - Medical studies including demographic data
Specification of Location Affinity

\[<\text{qowl-element} \text{name=\text{\"A3\\"} \ldots}>\ldots\ldots<\text{qos-constraints} \ldots><\text{qos-constraint} \text{name=\text{\"gridSiteAffinity\"}} \text{value=\text{\"SID\"}/><\text{qos-constraints}><\text{qowl-element}>\]

\[<\text{qowl-element} \text{name=\text{\"A7\\"} \ldots}>\ldots\ldots<\text{qos-constraints} \ldots><\text{qos-constraint} \text{name=\text{\"organisationAffinity\"}} \text{value=\text{\"OID\"}/><\text{qos-constraints}><\text{qowl-element}>\]

\[<\text{qowl-element} \text{name=\text{\"A11\\"} \ldots}>\ldots\ldots<\text{qos-constraints} \ldots><\text{qos-constraint} \text{name=\text{\"geographicAffinity\"}} \text{value=\text{\"GID\"}/><\text{qos-constraints}><\text{qowl-element}>\]

\[<\text{qowl-element} \text{name=\text{\"A1\\"} \ldots}>\ldots\ldots<\text{qos-constraints} \ldots><\text{qos-constraint} \text{name=\text{\"gridSiteAffinity\"}} \text{value=\text{\"SID\"}/><\text{qos-constraints}><\text{qowl-element}>\]

\[<\text{qowl-element} \text{name=\text{\"A6\\"} \ldots}>\ldots\ldots<\text{qos-constraints} \ldots><\text{qos-constraint} \text{name=\text{\"organisationAffinity\"}} \text{value=\text{\"OID\"}/><\text{qos-constraints}><\text{qowl-element}>\]

\[<\text{qowl-element} \text{name=\text{\"A9\\"} \ldots}>\ldots\ldots<\text{qos-constraints} \ldots><\text{qos-constraint} \text{name=\text{\"geographicAffinity\"}} \text{value=\text{\"GID\"}/><\text{qos-constraints}><\text{qowl-element}>\]

\[<\text{qowl-element} \text{name=\text{\"A12\\"} \ldots}>\ldots\ldots<\text{qos-constraints} \ldots><\text{qos-constraint} \text{name=\text{\"geographicAffinity\"}} \text{value=\text{\"GID\"}/><\text{qos-constraints}><\text{qowl-element}>\]

\[<\text{qowl-element} \text{name=\text{\"A13\\"} \ldots}>\ldots\ldots<\text{qos-constraints} \ldots><\text{qos-constraint} \text{name=\text{\"organisationAffinity\"}} \text{value=\text{\"OID\"}/><\text{qos-constraints}><\text{qowl-element}>\]

\[<\text{qowl-element} \text{name=\text{\"A14\\"} \ldots}>\ldots\ldots<\text{qos-constraints} \ldots><\text{qos-constraint} \text{name=\text{\"gridSiteAffinity\"}} \text{value=\text{\"SID\"}/><\text{qos-constraints}><\text{qowl-element}>\]
UML Modeling of QoS-aware Grid Workflows

- XML based workflow specification
  - error-prone and difficult for end users
  - Improvement by using a visual and intuitive modeling language
    → e.g. UML
- High level modeling based on UML
  - Activity diagrams
  - Visual modeling of QoS-aware Grid workflows
  - UML extensions mechanisms
  - Stereotypes and tagged values
  - UML based Domain Specific Language (DSL)
Customizing UML for Modeling of QoS-aware Grid Workflows

Definition of DSL e.g. Invoke Element

Usage of Invoke Element

"plain" UML
QoWL Representation with the UML-based DSL (I)

**Process**

<<Process>> SampleProcess

\{qosConstraints = qtiQTypes\}

**Switch**

<<Switch>> SampleSwitch

\{qosConstraints = qtiQTypes\}

Aggregation function <<Switch>>:

\[
time = \max \{\text{time}(B_i) \mid i=1,\ldots,k\}
\]

\[
price = \max \{\text{price}(B_i) \mid i=1,\ldots,k\}
\]
QoWL Representation with the UML-based DSL (II)

**Sequence**

<<Sequence>> SampleSequence

{qosConstraints = qtiQTypes}

<<Sequence>> Aggregation function:

\[ time = \sum_{i=1}^{n} \text{time}(A_i) \]

\[ price = \sum_{i=1}^{n} \text{price}(A_i) \]

**Flow**

<<Flow>> SampleFlow

{qosConstraints = qtiQTypes}

<<Flow>> Aggregation function:

\[ time = \max \{ \text{time}(A_i) | i=1,..,n \} \]

\[ price = \sum_{i=1}^{n} \text{price}(A_i) \]
QoS-aware Grid Workflow System

QoS-aware Grid Workflow Engine (QWE)
- XML parser / unparsers
- QoS Negotiator
- QoS Executer
- WF Planner (static/dynamic)
- Service Deployer and Generator

Grid Infrastructure
- Tomcat
- Apache AXIS

QoS-aware VGE Services
- Service 1 ... Service n

non VGE Services
- Service 1 ... Service n

GUI
- Teuta
- Model Traverser
- Model Checker
Specification of MFSS Workflow
<sequence name="FEM_Sequence">
  ...
  <copy name="CID">
    <from part="CID" variable="getCIDRequest"/>
    <to part="CID" variable="uploadOperation"/>
  </copy>
  ...
  <invoke inputVar="CID" name="StartOperation" operation="start"
      portType="ApplicationExecutor">
    <qos-constraints ReqDesc="maxilloReqDescVar">
      <registry wsdl="http://gescher.univie.ac.at:9357/registry/reg?wsdl"/>
      <registry wsdl="http://kim.univie.ac.at:9357/registry/reg?wsdl"/>
      <registry wsdl="http://aurora.tuwien.ac.at:9357/registry/reg?wsdl"/>
      <qos-constraint name="beginTime" value="2006-02-02T16:00:00.000+02:00"
          weight="0.3"/>
      <qos-constraint name="endTime" value="2006-02-02T18:00:00.000+02:00"/>
      <qos-constraint name="price" value="15" weight="0.7"/>
      <qos-constraint name="geographicAffinity" value="AT"/>
    </qos-constraints>
  </invoke>
  ...
  <invoke name="DownloadOperation" ... />
  ...
</sequence>


