A Distributed Data Flow Model for Composing Software Services

David W. Liu

May 9, 2003
Presentation Outline

• Motivation and Objectives
• Theoretical Analysis
• FICAS Service Composition Infrastructure
• Summary
Motivation and Objectives
Paradigm Shift in Software Engineering

1970 1990 2010

Integration

Coding

Courtesy of Professor Gio Wiederhold
Distributed Service Model

Megaservice: Conceptual Composition of Autonomous Services

Autonomous Service A
- Access Protocol A
- Operating System A
- Host A

Autonomous Service B
- Access Protocol B
- Operating System B
- Host B

Autonomous Service N
- Access Protocol N
- Operating System N
- Host N

Communication Network
Research Objectives

- Demonstrate the efficiency of the distributed data-flow model
- Define a framework for constructing software services
- Provide tools for composing software services
- Investigate techniques for performance optimization

(a) Centralized Data-flow Model
(b) Distributed Data-flow Model
Theoretical Analysis
Service Integration Models

(a) Centralized Control-flow and Centralized Data-flow Model (1C1D)

(b) Centralized Control-flow and Distributed Data-flow Model (1CnD)

(c) Distributed Control-flow and Centralized Data-flow Model (nC1D)

(d) Distributed Control-flow and Distributed Data-flow Model (nCnD)
System Modeling

\[ M: (\_, MP, \_) \]

\[ S_n: f_n(S_{l_n}, SP_n, SO_n) \]

\[ f: \text{ invocation frequency} \]

\[ S_l: \text{ input data size} \]

\[ SP: \text{ processing load} \]

\[ SO: \text{ output data size} \]

\[ CP: \text{ processing power} \]

\[ CM: \text{ communication bandwidth} \]

\[ \lambda: \text{ message header size} \]

\[ \delta: \text{ data distribution coefficient} \]

\[ \delta_{ij} = dd_{ij} / SO_i \]
Aggregated Cost

Aggregated cost = Amount of system resource consumed by a megaservice

- Centralized data-flow model incurs more data traffic
- Distributed data-flow model incurs more message overheads

\[ COST_c(M) - COST_d(M) = \beta \times \sum_{i=1}^{n} \left( D_{\text{data}}(i) + D_{\text{message}}(i) \right) \]

where \( D_{\text{data}}(i) = f_i \times SO_i \times (1 - \delta_{i0}) \)

\[ D_{\text{message}}(i) = \lambda \times \left( f_i \times (1 - m(i,0)) - \sum_{j=1}^{n} f_j \times m(i, j) \right) \]

\[ m(i, j) = \begin{cases} 0 & \text{if } \delta_{ij} = 0 \\ 1 & \text{if } \delta_{ij} \neq 0 \end{cases} \]
Messaging Cost for a Service Invocation

1CnD performs better, when data messages are much larger than control messages

(Data Message Size / Control Message Size)
Response Time

Response time = Time consumed to execute a megaservice

- Distributed data-flow model performs better if
  
  \[ CM_{ki} \geq CM_{0i} \text{ for all } k \neq 0 \text{ and } i \neq 0 \]

![Diagram of Time Marked Graph Representation of a Megaservice]

- Access links of megaservice
- Communication network among services
Computing Networks and Integration Models

(a) Internet and Corporate Intranet (Fit for distributed data-flow model)

(b) Dedicated Service Environment (Fit for centralized data-flow model)
Summary of Findings

Distributed data-flow model is suited for coarse grain service integration

Performance optimization for megaservice
  • Establish direct data exchanges among services
  • Distribute computations to where data is located

System architecture
  • Improve the communication network among the services for distributed data-flow model
  • Improve the access links of the megaservices for centralized data-flow model
FICAS
FICAS

Flow-based Infrastructure for Composing Autonomous Services

• Autonomous Services
  - Wrap legacy software applications
  - Provide an access protocol

• Buildtime Environment
  - Specify composition logic

• Runtime Environment
  - Coordinate service execution
  - Conduct performance optimization
Autonomous Services
Autonomous Service Metamodel

Service Core
- Provide service functionalities
- Wrap software applications

Two Data Containers
- Handle I/O data
- Enable distributed data-flows

Two Event Queues
- Handle inquiries and issue requests
- Support asynchronous invocations
- Form control-flows

Megaservice Controller
- Coordinate megaservice execution
Autonomous Service Access Protocol

ASAP
• Light-weight, asynchronous and event-based
• Define how autonomous services respond to events
• Use XML as transport medium for both control and data

Events
• **SETUP:** Initialize a service
• **TERMINATE:** Terminate a service
• **INVOKE:** Start execution of a service
• **MAPDATA:** Establish a data-flow between two services
• **CONTROLFILE:** Execute a megaservice
public interface ServiceCore
{
    public boolean setup (Container inc, Container outc, FlowId fid);

    public boolean execute (Container inc, Container outc, FlowId fid);

    public boolean terminate (Container inc, Container outc, FlowId fid);
}
Buildtime Environment
Composition
- Invocation of services
- Dependencies among services
- Process flow of services

Computation
- Processing of service data
Compositional Language for Autonomous Services
- High-level and declarative
- Based on CLAM developed in CHAIMS
- Simple (for domain experts, NOT technical experts)
- Separation between composition and computation

Features
- Decomposition of a CALL statement into 4 primitives
  - SETUP, INVOKE, EXTRACT, TERMINATE
- Control primitives
  - IF ... THEN ... ELSE
  - WHILE
Sample CLAS Program

SchedulingDemo http://ficas.stanford.edu/Megaprogram
{
    /* Setup Services */
    psl_svc = SETUP("SIPsl")
    p3_svc = SETUP("SIP3")
    notification_svc = SETUP("SINotification")

    /* Invoke services */
    psl = psl_svc.INVOKE("to-psl", "CEIL")
    ceil = psl.EXTRACT()
    p3 = p3_svc.INVOKE("reschedule", ceil)
    ceil2 = p3.EXTRACT()
    oracle = psl_svc.INVOKE("to-oracle", ceil2)
    status = oracle.EXTRACT()
    IF (status == "SUCCESS")
    THEN {
        notif = notification_svc.INVOKE("171.64.55.32", 8250, status)
    }
    ...
Mobile Class

Mobile Class
- Java-based and reusable
- Perform complex computations

Usage of Mobile Class
- Arithmetic operation
- Relational operation
- Data aggregation and abstraction
- Type conversion

```java
/* A mobile class for type conversion */
public class int2float implements MobileClass {
    public DataElement execute(Vector params) {
        DataElement arg = (DataElement) params.firstElement();
        int val = arg.getIntValue();
        return new DataElement().setValue(new Double(val).doubleValue());
    }
}

/* Using mobile class in a CLAS program */
floatnum = MCLASS("int2float", num)
```
Mobile Class for Type Mediation

(a) Type Brokers

(b) Type Mediation Mobile Classes
Runtime Environment
Architecture of Runtime Environment

- Megaservice Controller
- Service Core
- Autonomous Service Wrapper
- Communication Network
- Autonomous Service
- Directory
- Mobile Classes
- From FICAS Buildtime
- FICAS Control Sequence
### FICAS Control Sequence

...  

```
<INVOKE>
  <INVOCATIONHANDLE>Invocation1</INVOCATIONHANDLE>
  <SERVICEHANDLE>Service1</SERVICEHANDLE>
</INVOKE>

<INVOKE>
  <INVOCATIONHANDLE>Invocation2</INVOCATIONHANDLE>
  <SERVICEHANDLE>Service2</SERVICEHANDLE>
</INVOKE>

<EXTRACT>
  <VARIABLE>A</VARIABLE>
  <INVOCATIONHANDLE>Invocation1</INVOCATIONHANDLE>
</EXTRACT>

<EXTRACT>
  <VARIABLE>B</VARIABLE>
  <INVOCATIONHANDLE>Invocation2</INVOCATIONHANDLE>
</EXTRACT>

<INVOKE>
  <INVOCATIONHANDLE>Invocation3</INVOCATIONHANDLE>
  <SERVICEHANDLE>Service3</SERVICEHANDLE>
  <VALUELIST>
    <VARIABLE>A</VARIABLE>
    <VARIABLE>B</VARIABLE>
  </VALUELIST>
</INVOKE>

...```
Invocation1 = Service1.INVOKE();
Invocation2 = Service2.INVOKE();
A = Invocation1.EXTRACT();
B = Invocation2.EXTRACT();

Invocation3 = Service3.INVOKE(A, B);
C = Invocation3.EXTRACT();

Invocation4 = Service4.INVOKE(C)
D = Invocation4.EXTRACT();
Event Dependency Graph (1CnD)

Service 1 → MegaService
Service 2 → MegaService
Service 3 → MegaService
Service 4 → MegaService

INVOKE (Service1)

MAPDATA (A, Service1, Service3)

INVOKE (Service3)

MAPDATA (C, Service3, Service4)

INVOKE (Service4)

MAPDATA (D, Service4, Megaservice)
Performance Evaluation – SOAP vs. FICAS

MultiService
{
  a = S1(size)
  S2(a)
}

SingleService
{
  a = S1(size)
}

Mege Service

Switch

S1 produces a string

S2 consumes a string

(LAN) in = 10 mbps; out = 10 mbps
(Wireless) in = 2 mbps; out = 0.5 mbps
Performance in LAN Setting

- SOAP (SingleService)
- SOAP (MultiService)
- FICAS (MultiService)

SOAP incurs higher data-flow cost

FICAS incurs higher control-flow cost

Megaservice Execution Time vs. Data Volume (KB)
Performance in Wireless Setting

SOAP creates bottleneck on the megaservice communication link.

FICAS is little affected since data-flows are distributed.

SOAP (LAN)    SOAP (802.11b)    FICAS (LAN)    FICAS (802.11b)
Example Megaservice Utilizing a Mobile Class

Invocation1 = S1.INVOKE(size)
A = Invocation1.EXTRACT()
B = MCLASS("FILTER", A)
Invocation2 = S2.INVOKE(B)
Placement of Mobile Class

(a) Placing FILTER at S1
(b) Placing FILTER at S2
(c) Using an autonomous service

Service Invocation

Data-flow
Performance Comparison for Mobile Class

Mobile class placement affects megaservice performance. Mobile class is more efficient than autonomous service.
Infrastructure for Engineering Services
An Integrated Service Environment

Integrated Work Processes

Communication Network

Mobile Classes for Data Integration

Designers
On Site Personnel
Project Managers

Modeilling Tools
Autonomous Service Wrapper

Project Planning Tools
Autonomous Service Wrapper

Spread sheets
Autonomous Service Wrapper
Data Mediation Among the Tools

Related work by Jim Cheng at Engineering Informatics Group, Stanford University
Review Design in 4D Viewer
## Review Schedule in Primavera

### Activity ID | Activity Description | Orig Dur | Early Start | Early Finish
--- | --- | --- | --- | ---
FRP Slab on Metal Deck

**18T1-32101** | FRP SODM 1st Lift T 1-3, Seq 22-24 Elem1 | 12 | 07MAR01 | 22MAR01

**18T2-32101** | FRP SODM 1st Lift Seq 25-27 Roof T 4-6 Elem1 | 10 | 20MAR01 | 02APR01

**18T3-32101** | FRP SODM 1st Li Roof T7-Can Elem 1 Seq 34 | 10 | 03APR01 | 16APR01

Cure Concrete

**18T1-32102** | CureConcrete Roof T 1-3 Seq 22-24 Elem1 | 14 | 23MAR01 | 05APR01

**18T2-32102** | CureConcrete Seq 25-27 Roof T 4-6 Elem1 | 14 | 06APR01 | 19APR01

**18T3-32102** | CureConcrete Roof T7-Can Elem 1 Seq 34 | 14 | 20APR01 | 03AY01

Form/Rebar/Pour SODM 2nd Lift

**18T1-32331** | FRP SODM 2nd Li Roof Seq 22-24, T1-3 Elem1 | 9 | 31JAN01 | 12FEB01

**18T2-32331** | FRP SODM Seq 25-27 2nd Li Roof T 4-6 Elem1 | 9 | 13FEB01 | 23FEB01

**18T3-32331** | FRP SODM 2nd Li Roof T7-Can Elem 1 Seq 34 | 9 | 28FEB01 | 08MAR01

Erect Secondary/Floor Frng Steel

**18T1-333201** | Erect Seq 22 T1 - Roof Elem | 1 | 31JAN01 | 31JAN01

**18T2-333201** | Erect Seq 23 T2 - Roof Elem | 1 | 05FEB01 | 05FEB01

**18T3-333201** | Erect Seq 24 T3 - Roof Elem | 1 | 07FEB01 | 07FEB01

**18T4-333201** | Erect Seq 25 T4 - Roof Elem | 1 | 09FEB01 | 09FEB01

**18T5-333201** | Erect Seq 26 T5 - Roof Elem | 1 | 13FEB01 | 13FEB01

**18T6-333201** | Erect Seq 27 T6 - Roof Elem | 1 | 16FEB01 | 16FEB01

**18T7-333201** | Erect Seq 34 Truss 7 Roof N Half Elem | 1 | 19FEB01 | 19FEB01

Plumb & Align Ceiling Steel

**17T1-33221** | Erect Top/Bot Frng T 1 Lvl 7 Elem | 2 | 01FEB01 | 02FEB01

**17T2-33221** | Erect Top/Bot Frng T 2 Lvl 7 Elem | 1 | 06FEB01 | 06FEB01

**17T3-33221** | Erect Top/Bot Frng T 3 Lvl 7 Elem | 1 | 08FEB01 | 08FEB01

**17T4-33221** | Erect Top/Bot Frng T 4 Lvl 7 Elem | 1 | 12FEB01 | 12FEB01

**17T5-33221** | Erect Top/Bot Frng T 5 Lvl 7 Elem | 2 | 14FEB01 | 15FEB01

**17T6-33221** | Erect Top/Bot Frng T 6 Lvl 7 Elem | 2 | 19FEB01 | 20FEB01

Legend:
- FRP SODM 1st Lift T 1-3, Seq 22-24 Elem1
- FRP SODM 1st Lift Seq 25-27 Roof T 4-6 Elem1
- FRP SODM 1st Li Roof T7-Can Elem 1 Seq 34
- CureConcrete Roof T 1-3 Seq 22-24 Elem1
- CureConcrete Seq 25-27 Roof T 4-6 Elem1
- CureConcrete Roof T7-Can Elem 1 Seq 34
- FRP SODM 2nd Li Roof Seq 22-24, T1-3 Elem1
- FRP SODM Seq 25-27 2nd Li Roof T 4-6 Elem1
- FRP SODM 2nd Li Roof T7-Can Elem 1 Seq 34
- Erect Seq 22 T1 - Roof Elem
- Erect Seq 23 T2 - Roof Elem
- Erect Seq 24 T3 - Roof Elem
- Erect Seq 25 T4 - Roof Elem
- Erect Seq 26 T5 - Roof Elem
- Erect Seq 27 T6 - Roof Elem
- Erect Seq 34 Truss 7 Roof N Half Elem
- Erect Top/Bot Frng T 1 Lvl 7 Elem
- Erect Top/Bot Frng T 2 Lvl 7 Elem
- Erect Top/Bot Frng T 3 Lvl 7 Elem
- Erect Top/Bot Frng T 4 Lvl 7 Elem
- Erect Top/Bot Frng T 5 Lvl 7 Elem
- Erect Top/Bot Frng T 6 Lvl 7 Elem
Review Schedule in Microsoft Project
View Schedule on Site

http://med...!!  History

SCHEDULE

Review the schedule and make appropriate updates by changing the value in duration:

<table>
<thead>
<tr>
<th>SCHEDULEID</th>
<th>STARTDATE</th>
<th>DURATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>18T1-33201</td>
<td>01-31-2001</td>
<td>1</td>
</tr>
<tr>
<td>18T1-33241</td>
<td>02-01-2001</td>
<td></td>
</tr>
</tbody>
</table>
Modifying Schedule On-site

Review the schedule and make appropriate updates by changing the value in duration:

<table>
<thead>
<tr>
<th>SCHEDULEID</th>
<th>STARTDATE</th>
<th>DURATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>18T1-33201</td>
<td>01-31-2001</td>
<td>40</td>
</tr>
<tr>
<td>18T1-33241</td>
<td>02-01-2001</td>
<td></td>
</tr>
</tbody>
</table>

Change duration of activity 18T1-33201 ("Erect Roof Element 1") from 1 day to 40 days.
Invoke Rescheduling Megaservice

Primavera
Scheduling Service

PSL
Model Service

Excel Service

Change Notify Service

Network

Rescheduling MegaService

RescheduleService {
  model = PSLModel(modelname, 'oracle-to-psl')
  new_model = P3Scheduling(model, 'reschedule')
  PSLModel(new_model, 'psl-to-oracle')
  excel_data = MCLASS("psltoexcel", new_model)
  ExcelService(excel_data, 'show')
  ChangeNotify(modelname)
}
Review Modified Schedule in Excel

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>148</td>
<td>17T7-61511</td>
<td>8/30/2001</td>
<td>28</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>149</td>
<td>17T7-61900</td>
<td>4/26/2001</td>
<td>3</td>
<td>0</td>
<td>83</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>17T8-61501</td>
<td>5/5/2001</td>
<td>2</td>
<td>10</td>
<td>186</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>151</td>
<td>17T8-61511</td>
<td>10/10/2001</td>
<td>15</td>
<td>60</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>152</td>
<td>17T8-61900</td>
<td>5/1/2001</td>
<td>4</td>
<td>0</td>
<td>154</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>153</td>
<td>1800-71151</td>
<td>1/31/2001</td>
<td>6</td>
<td>0</td>
<td>315</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>154</td>
<td>1800-71201</td>
<td>2/1/2001</td>
<td>8</td>
<td>0</td>
<td>315</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>155</td>
<td>18T1-32101</td>
<td>5/1/2001</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>156</td>
<td>18T1-32102</td>
<td>5/17/2001</td>
<td>14</td>
<td>0</td>
<td>315</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>157</td>
<td>18T1-32331</td>
<td>1/31/2001</td>
<td>9</td>
<td>0</td>
<td>298</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>158</td>
<td>18T1-33201</td>
<td>1/31/2001</td>
<td>40</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>159</td>
<td>18T1-33401</td>
<td>4/20/2001</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>160</td>
<td>18T2-32101</td>
<td>5/14/2001</td>
<td>10</td>
<td>0</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>161</td>
<td>18T2-32102</td>
<td>5/31/2001</td>
<td>14</td>
<td>0</td>
<td>315</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>162</td>
<td>18T2-32331</td>
<td>2/13/2001</td>
<td>9</td>
<td>0</td>
<td>298</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>163</td>
<td>18T2-33201</td>
<td>3/30/2001</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>164</td>
<td>18T2-33401</td>
<td>5/1/2001</td>
<td>9</td>
<td>0</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>165</td>
<td>18T3-32101</td>
<td>5/29/2001</td>
<td>10</td>
<td>0</td>
<td>144</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>166</td>
<td>18T3-33201</td>
<td>4/3/2001</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Affected activity 18T1-33201
Review Changed Activities in Browser

<table>
<thead>
<tr>
<th>CEIL</th>
<th>8ST1-3234</th>
<th>01-31-2009 05:00:00</th>
<th>2</th>
<th>Update</th>
<th>2</th>
<th>209</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEIL</td>
<td>8ST1-3234</td>
<td>01-31-2009 05:00:00</td>
<td>2</td>
<td>Update</td>
<td>2</td>
<td>209</td>
</tr>
<tr>
<td>CEIL</td>
<td>8ST1-3234</td>
<td>01-31-2009 05:00:00</td>
<td>2</td>
<td>Update</td>
<td>2</td>
<td>209</td>
</tr>
<tr>
<td>CEIL</td>
<td>8ST1-3234</td>
<td>01-31-2009 05:00:00</td>
<td>2</td>
<td>Update</td>
<td>2</td>
<td>209</td>
</tr>
<tr>
<td>CEIL</td>
<td>8ST1-3234</td>
<td>01-31-2009 05:00:00</td>
<td>2</td>
<td>Update</td>
<td>2</td>
<td>209</td>
</tr>
<tr>
<td>CEIL</td>
<td>8ST1-3234</td>
<td>01-31-2009 05:00:00</td>
<td>2</td>
<td>Update</td>
<td>2</td>
<td>209</td>
</tr>
<tr>
<td>CEIL</td>
<td>8ST1-3234</td>
<td>01-31-2009 05:00:00</td>
<td>2</td>
<td>Update</td>
<td>2</td>
<td>209</td>
</tr>
<tr>
<td>CEIL</td>
<td>8ST1-3234</td>
<td>01-31-2009 05:00:00</td>
<td>2</td>
<td>Update</td>
<td>2</td>
<td>209</td>
</tr>
<tr>
<td>CEIL</td>
<td>8ST1-3234</td>
<td>01-31-2009 05:00:00</td>
<td>2</td>
<td>Update</td>
<td>2</td>
<td>209</td>
</tr>
<tr>
<td>CEIL</td>
<td>8ST1-3234</td>
<td>01-31-2009 05:00:00</td>
<td>2</td>
<td>Update</td>
<td>2</td>
<td>209</td>
</tr>
<tr>
<td>CEIL</td>
<td>8ST1-3234</td>
<td>01-31-2009 05:00:00</td>
<td>2</td>
<td>Update</td>
<td>2</td>
<td>209</td>
</tr>
<tr>
<td>CEIL</td>
<td>8ST1-3234</td>
<td>01-31-2009 05:00:00</td>
<td>2</td>
<td>Update</td>
<td>2</td>
<td>209</td>
</tr>
<tr>
<td>CEIL</td>
<td>8ST1-3234</td>
<td>01-31-2009 05:00:00</td>
<td>2</td>
<td>Update</td>
<td>2</td>
<td>209</td>
</tr>
<tr>
<td>CEIL</td>
<td>8ST1-3234</td>
<td>01-31-2009 05:00:00</td>
<td>2</td>
<td>Update</td>
<td>2</td>
<td>209</td>
</tr>
</tbody>
</table>

Actual change

Affected Activities

[Diagram showing the file and the actual change highlighted]
Review Modified Schedule in Primavera

<table>
<thead>
<tr>
<th>Activity ID</th>
<th>Activity Description</th>
<th>Orig Dur</th>
<th>Early Start</th>
<th>Early Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>18T1-32101</td>
<td>FRP SOMD: 1st Lift, Seq 22-24</td>
<td>12</td>
<td>01NAY01</td>
<td>16MAY01</td>
</tr>
<tr>
<td>18T2-32101</td>
<td>FRP SOMD: 1st Lift, Seq 25-27</td>
<td>10</td>
<td>14NAY01</td>
<td>25MAY01</td>
</tr>
<tr>
<td>18T3-32101</td>
<td>FRP SOMD: 1st Lift, Seq 26-27</td>
<td>10</td>
<td>29NAY01</td>
<td>11JUN01</td>
</tr>
</tbody>
</table>

**Updated activity**

<table>
<thead>
<tr>
<th>Activity ID</th>
<th>Activity Description</th>
<th>Orig Dur</th>
<th>Early Start</th>
<th>Early Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>18T1-32102</td>
<td>Cure Concrete, Seq 22-24</td>
<td>14</td>
<td>17NAY01</td>
<td>30MAY01</td>
</tr>
<tr>
<td>18T2-32102</td>
<td>Cure Concrete, Seq 25-27</td>
<td>14</td>
<td>31NAY01</td>
<td>13JUN01</td>
</tr>
<tr>
<td>18T3-32102</td>
<td>Cure Concrete, Seq 26-27</td>
<td>14</td>
<td>14JUN01</td>
<td>27JUN01</td>
</tr>
</tbody>
</table>

Form/Rebar/Pour SOMD 2nd Lift

<table>
<thead>
<tr>
<th>Activity ID</th>
<th>Activity Description</th>
<th>Orig Dur</th>
<th>Early Start</th>
<th>Early Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>18T1-32331</td>
<td>FRP SOMD: 2nd Lift, Seq 22-24</td>
<td>9</td>
<td>31JAN01</td>
<td>12FEB01</td>
</tr>
<tr>
<td>18T2-32331</td>
<td>FRP SOMD: 2nd Lift, Seq 25-27</td>
<td>9</td>
<td>13FEB01</td>
<td>23FEB01</td>
</tr>
<tr>
<td>18T3-32331</td>
<td>FRP SOMD: 2nd Lift, Seq 26-27</td>
<td>9</td>
<td>26FEB01</td>
<td>08MAR01</td>
</tr>
</tbody>
</table>

Erect Secondary/Floor Framing Steel

<table>
<thead>
<tr>
<th>Activity ID</th>
<th>Activity Description</th>
<th>Orig Dur</th>
<th>Early Start</th>
<th>Early Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>18T1-33201</td>
<td>Erect Seq 22 T1 - Roof Elem1</td>
<td>40</td>
<td>30MAR01</td>
<td>27MAR01</td>
</tr>
<tr>
<td>18T2-33201</td>
<td>Erect Seq 23 T2 - Roof Elem1</td>
<td>30</td>
<td>30MAR01</td>
<td>30MAR01</td>
</tr>
<tr>
<td>18T3-33201</td>
<td>Erect Seq 24 T3 - Roof Elem1</td>
<td>1</td>
<td>03APR01</td>
<td>03APR01</td>
</tr>
<tr>
<td>18T4-33201</td>
<td>Erect Seq 25 T4 - Roof Elem1</td>
<td>1</td>
<td>05APR01</td>
<td>05APR01</td>
</tr>
<tr>
<td>18T5-33201</td>
<td>Erect Seq 26 T5 - Roof Elem1</td>
<td>1</td>
<td>09APR01</td>
<td>09APR01</td>
</tr>
<tr>
<td>18T6-33201</td>
<td>Erect Seq 27 T6 - Roof Elem1</td>
<td>1</td>
<td>12APR01</td>
<td>12APR01</td>
</tr>
<tr>
<td>18T7-33201</td>
<td>Erect Seq 34 Truss 7 Roof N Half Elem1</td>
<td>1</td>
<td>13APR01</td>
<td>13APR01</td>
</tr>
</tbody>
</table>

Plumb & Align Ceiling Steel

<table>
<thead>
<tr>
<th>Activity ID</th>
<th>Activity Description</th>
<th>Orig Dur</th>
<th>Early Start</th>
<th>Early Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>18T1-33221</td>
<td>Erect Top/Bot Framing T 1 Lvl 7 Elem1</td>
<td>2</td>
<td>28MAR01</td>
<td>29MAR01</td>
</tr>
<tr>
<td>18T2-33221</td>
<td>Erect Top/Bot Framing T 2 Lvl 7 Elem1</td>
<td>1</td>
<td>02APR01</td>
<td>02APR01</td>
</tr>
<tr>
<td>18T3-33221</td>
<td>Erect Top/Bot Framing T 3 Lvl 7 Elem1</td>
<td>1</td>
<td>04APR01</td>
<td>04APR01</td>
</tr>
<tr>
<td>18T4-33221</td>
<td>Erect Top/Bot Framing T 4 Lvl 7 Elem1</td>
<td>1</td>
<td>06APR01</td>
<td>06APR01</td>
</tr>
<tr>
<td>18T5-33221</td>
<td>Erect Top/Bot Framing T 5 Lvl 7 Elem1</td>
<td>1</td>
<td>10APR01</td>
<td>11APR01</td>
</tr>
<tr>
<td>18T6-33221</td>
<td>Erect Top/Bot Framing T 6 Lvl 7 Elem1</td>
<td>1</td>
<td>13APR01</td>
<td>16APR01</td>
</tr>
</tbody>
</table>
Roof construction is delayed.
Review Modified Schedule in Project

- Actual change
- Affected activities
Summary
Contributions

- Data-flow distribution improves megaservice performance
- Distributed data-flow model is supported in service composition
  - Separate data from controls in services
  - Separate computation from composition
  - Establish direct data communications among services
- Distribution of computations facilities service composition
  - Mobile class allows performance optimization
  - Active mediation enhances the flexibility of services
- FICAS provides comprehensive support for service composition
Publications


Acknowledgements

• Defense committee
• Members of Engineering Informatics Group
• Research support
  – Dr. Ram D. Sriram, NIST
  – Dr. Charles S. Han, Autodesk
  – Mr. Jim Cheng, Stanford University
  – Prof. Martin Fisher and his research group, Stanford University
• This work is supported in part by
  – Air Force (Grant F49620-97-1-0339, Grant F30602-00-2-0594)
  – CIFE, Stanford University
  – Product Engineering Program at NIST
  – Technology for Education 2000 Equipment Grant, Intel Corporation