Stanford University Ph.D. Oral Examination

Department of Electrical Engineering

A Distributed Data Flow Model for Composing Software Services

David W. Liu

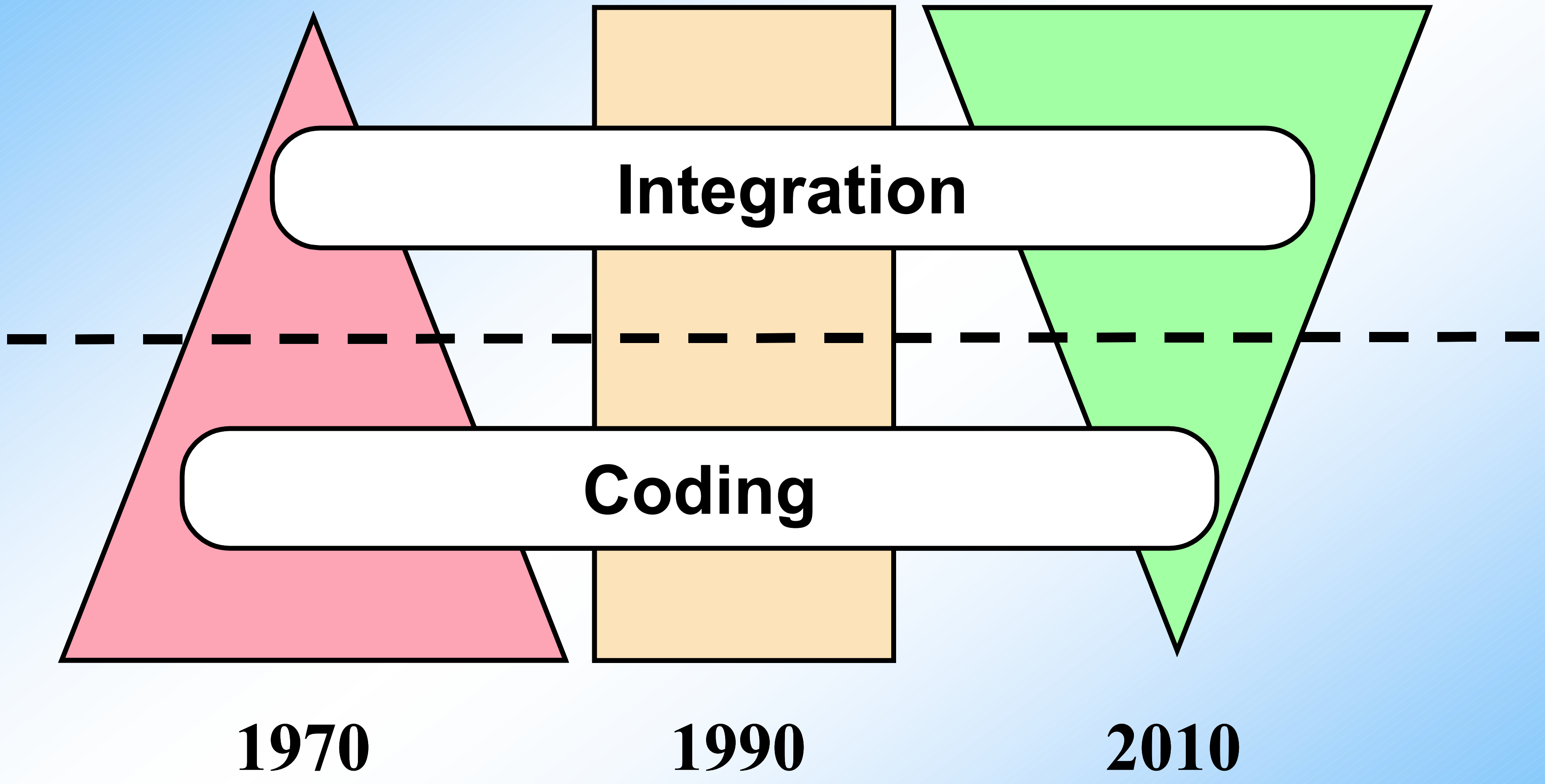
May 9, 2003

Presentation Outline

- Motivation and Objectives
- Theoretical Analysis
- FICAS Service Composition Infrastructure
- Summary

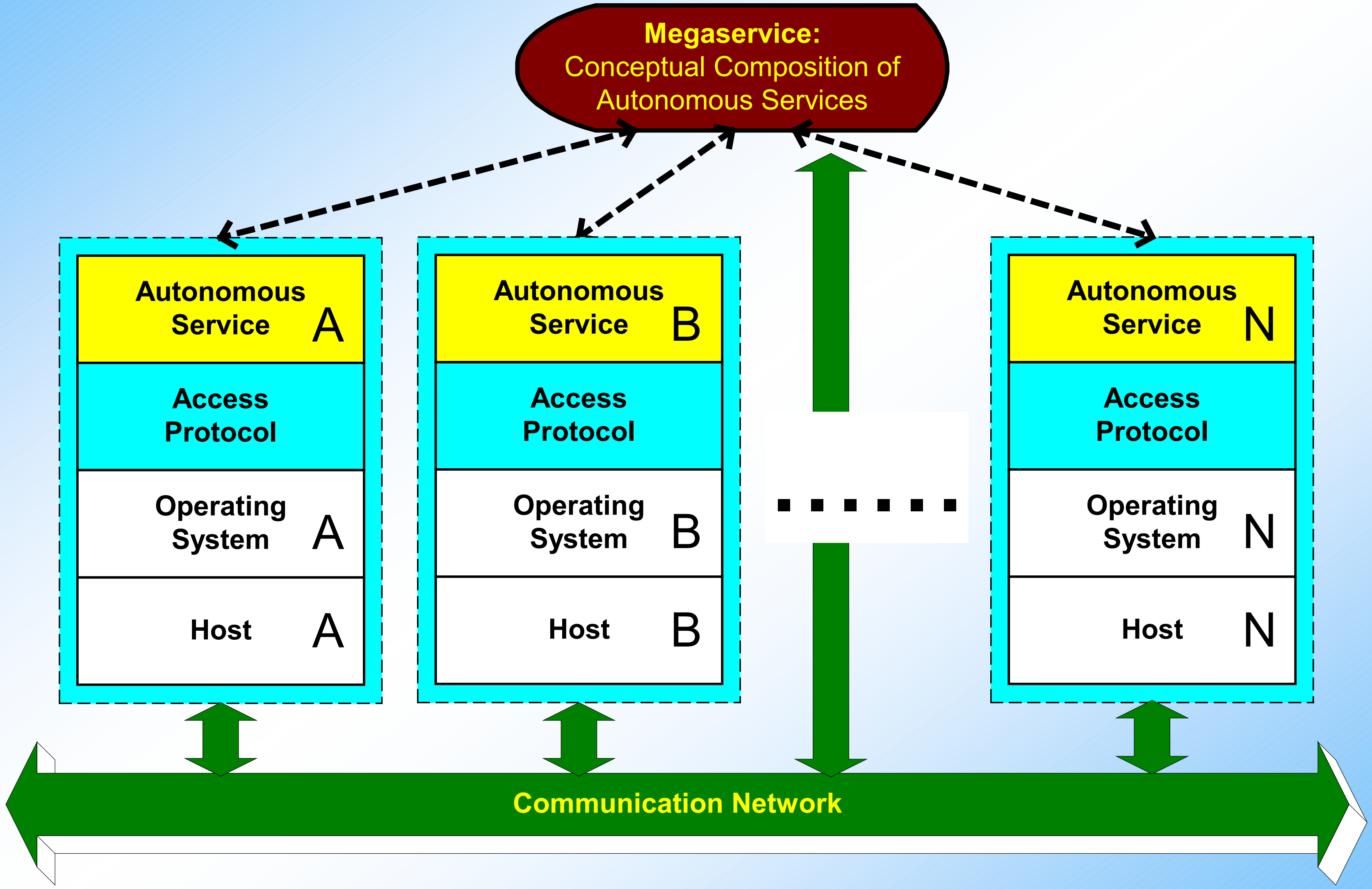
Motivation and Objectives

Paradigm Shift in Software Engineering



Courtesy of Professor Gio Wiederhold

Distributed Service Model



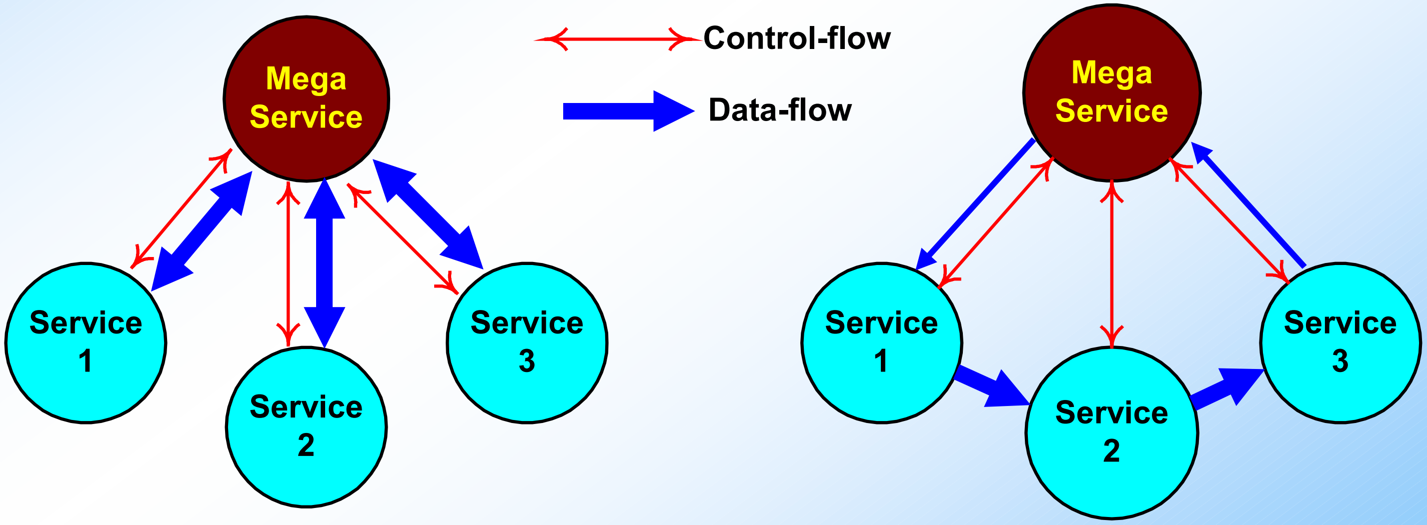
Megaservice:
Conceptual Composition of
Autonomous Services

Autonomous Service A	**Autonomous Service** B	......	**Autonomous Service** N
Access Protocol	**Access Protocol**		**Access Protocol**
Operating System A	**Operating System** B		**Operating System** N
Host A	**Host** B		**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

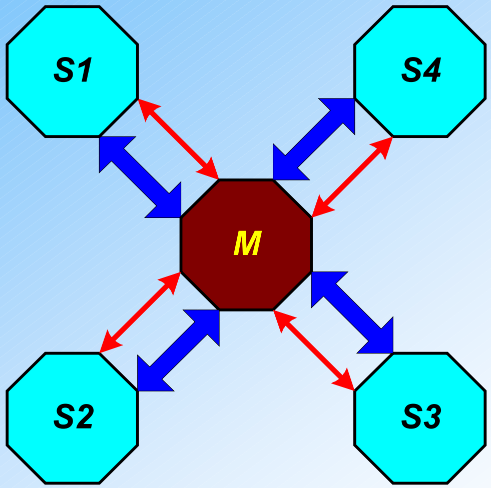


(a) Centralized Data-flow Model

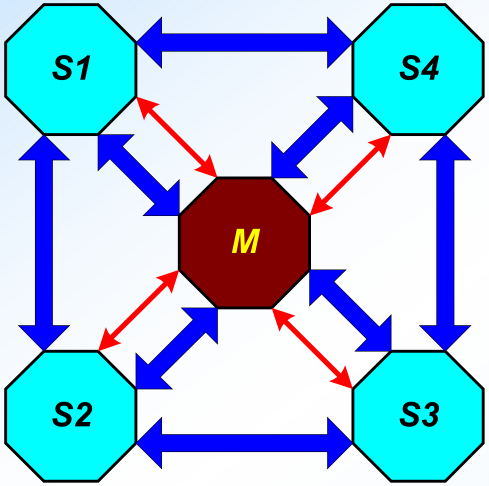
(b) Distributed Data-flow Model

Theoretical Analysis

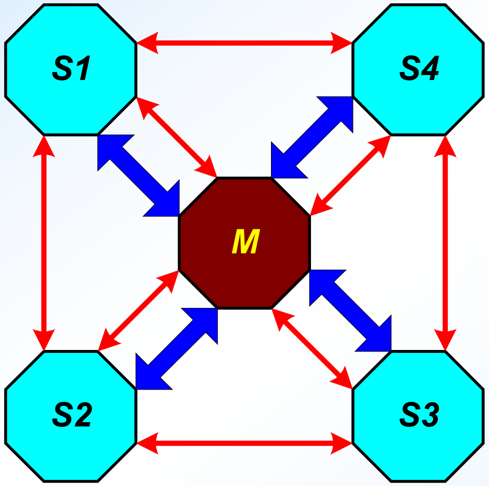
Service Integration Models



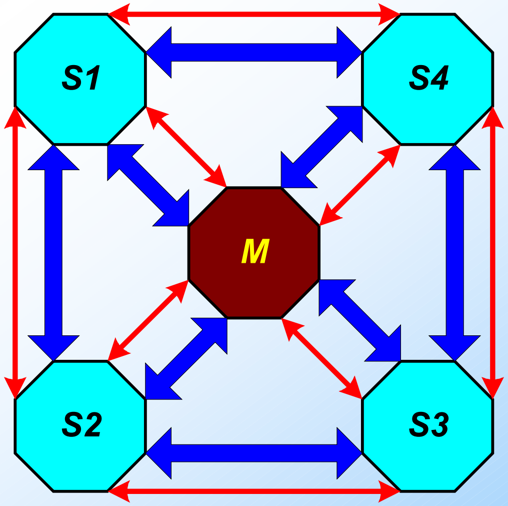
(a) Centralized Control-flow and Centralized Data-flow Model (1C1D)



(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)

↔

Control-flows

⬌

Data-flows

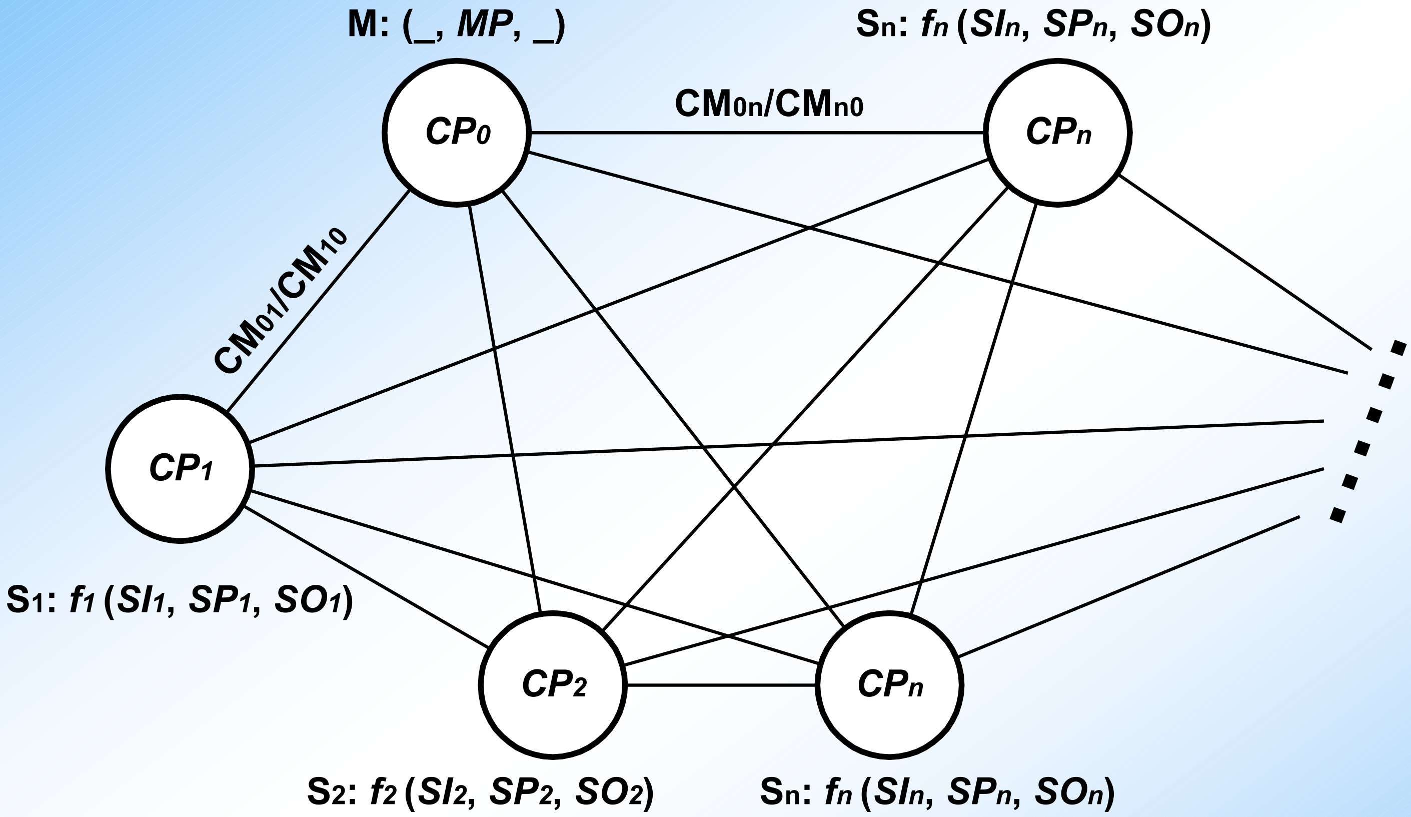
M

Megaservice

S

Autonomous Services

System Modeling


M: (_, *MP*, _)
S_n: f_n (SI_n, SP_n, SO_n)
CM_{0n}/CM_{n0}
CP_0
CP_n
CM_{01}/CM_{10}
CP_1
S_1: f_1 (SI_1, SP_1, SO_1)
CP_2
CP_n
S_2: f_2 (SI_2, SP_2, SO_2)
S_n: f_n (SI_n, SP_n, SO_n)

f:	invocation frequency	*CP*:	processing power
SI:	input data size	*CM*:	communication bandwidth
SP:	processing load	λ:	message header size
SO:	output data size	δ:	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

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

Weight of communication cost

Output data from service

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

Portion returned to megaservice

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

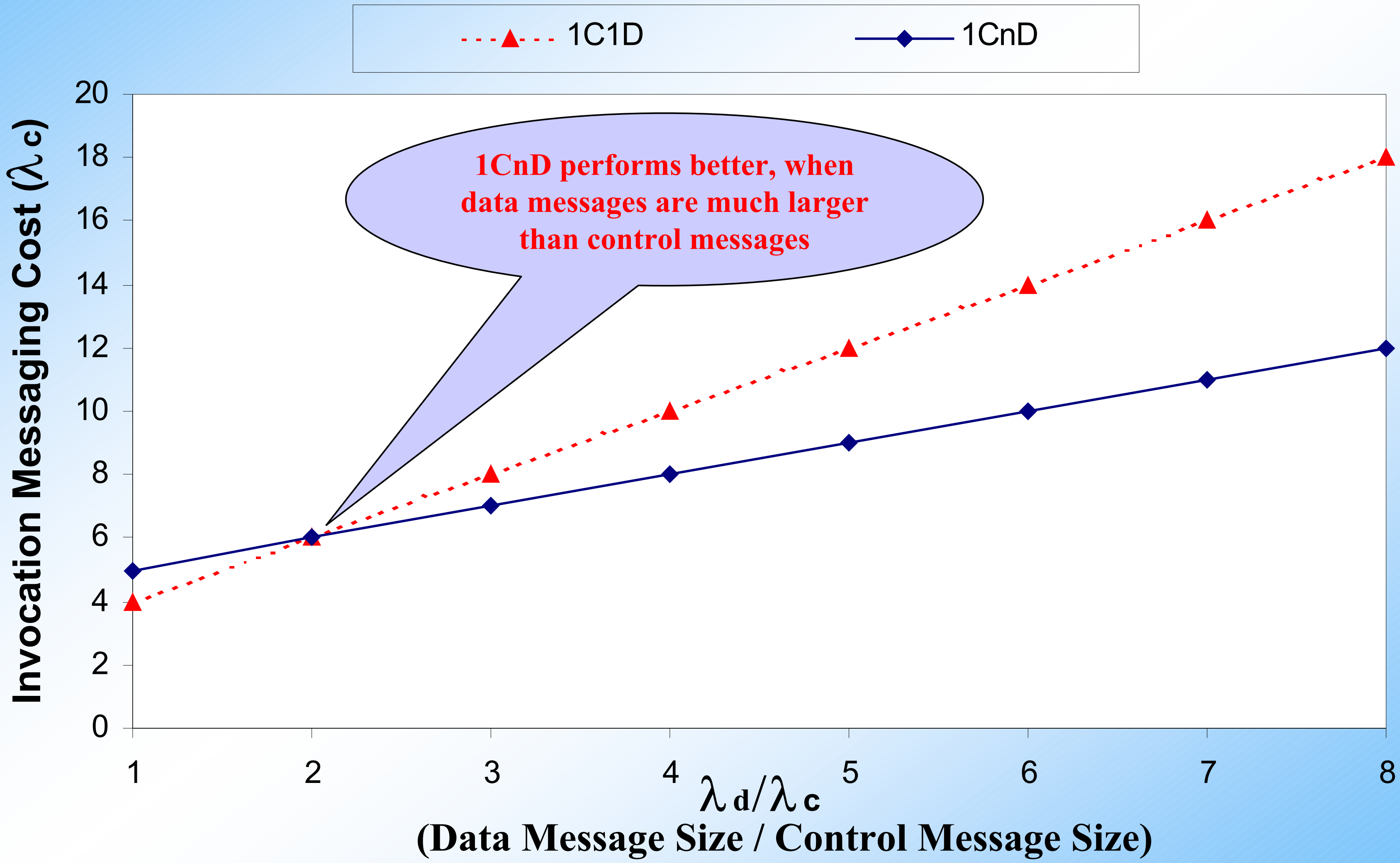
$$m(i,j) = \begin{cases} 0 & if \quad \delta_{ij} = 0 \\ 1 & if \quad \delta_{ij} \neq 0 \end{cases}$$

Data messages among services

Data messages returned to megaservice

Data message overhead

Messaging Cost for a Service Invocation



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

Response Time

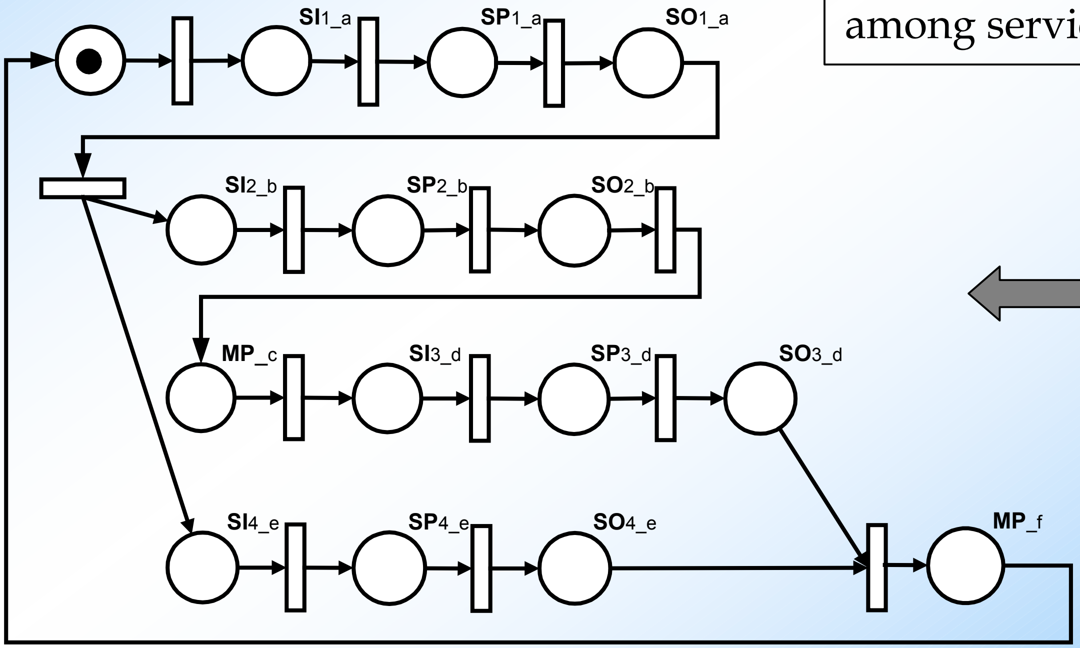
Response time = Time consumed to execute a megaservice

- Distributed data-flow model performs better if

$CM_{ki} \geq CM_{0i}$ for all $k \neq 0$ and $i \neq 0$

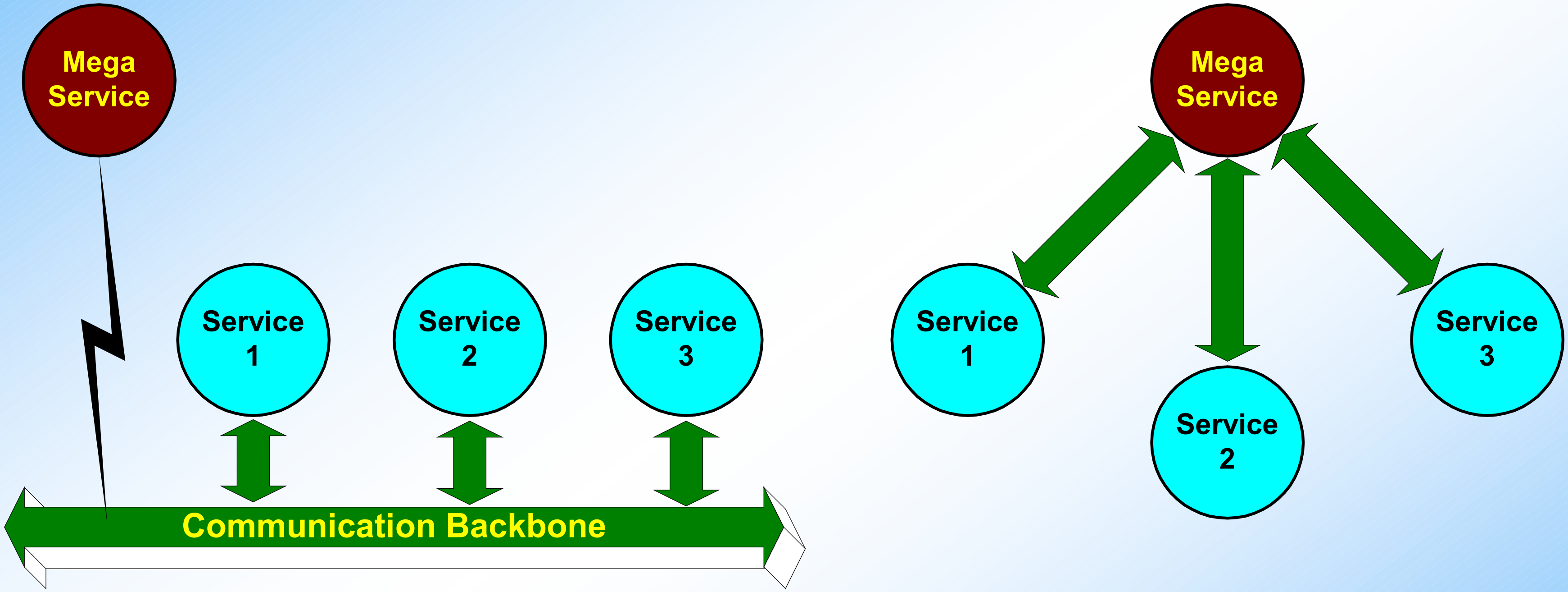
Access links of megaservice

Communication network among services



Time Marked Graph Representation of a Megaservice

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

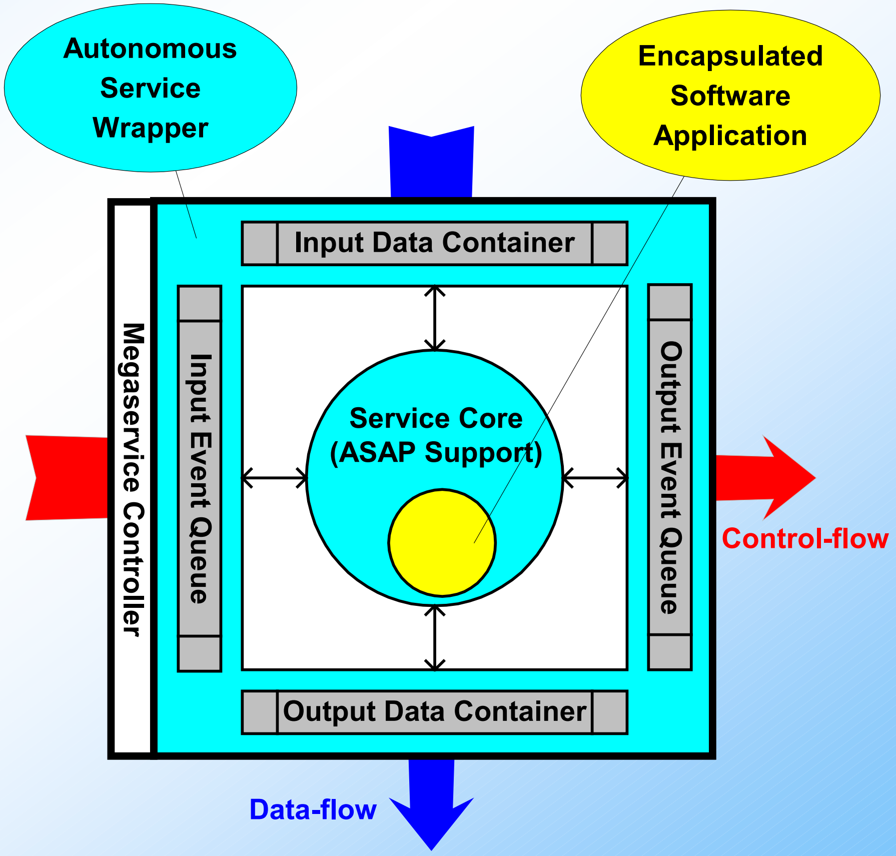
- Handle I/O data
- Enable distributed data-flows

Two Event Queues

- Handle inqueries and issue requests
- Support asynchronous invocations
- Form control-flows

Megaservice Controller

- Coordinate megaservice execution



Autonomous Service Access Protocol

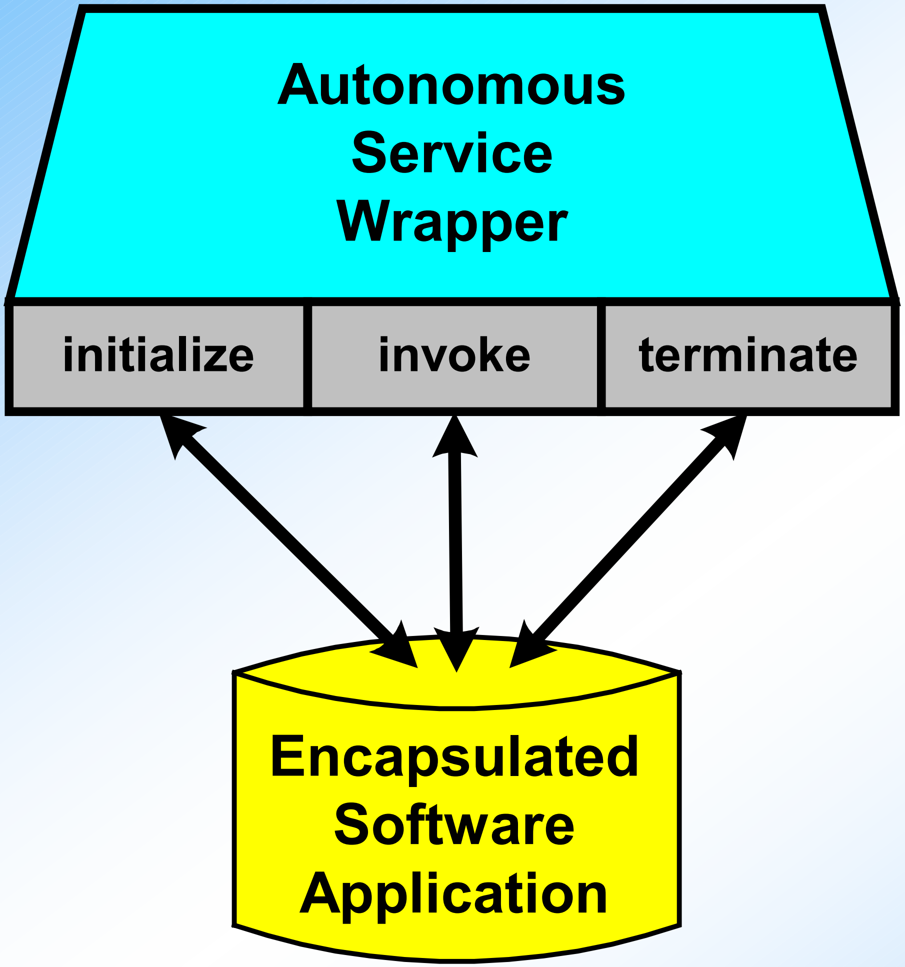
ASAP

- 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

Autonomous Service Wrapper



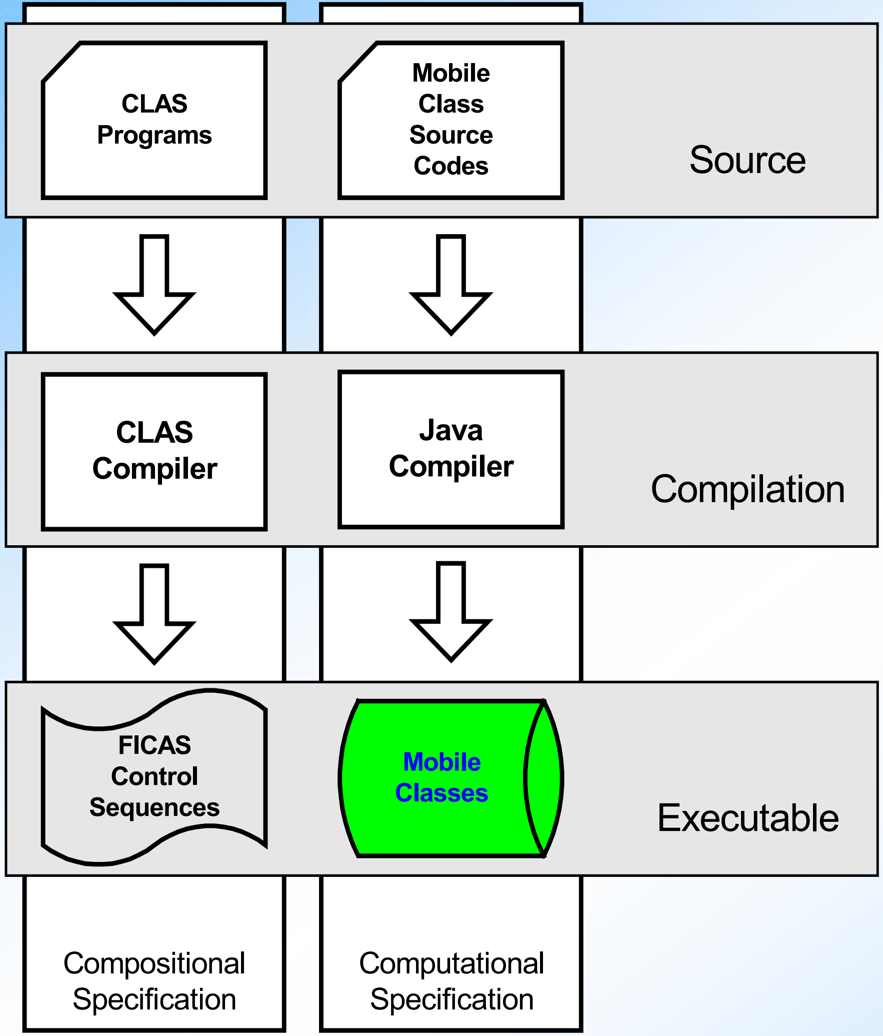
```
public interface ServiceCore
{
  public boolean setup (
    Container inc,
    Container outc,
    FlowId fid );

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

  public boolean terminate (
    Container inc,
    Container outc,
    FlowId fid );
}
```

Buildtime Environment

Architecture of Buildtime Environment



Composition

- Invocation of services
- Dependencies among services
- Process flow of services

Computation

- Processing of service data

CLAS

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

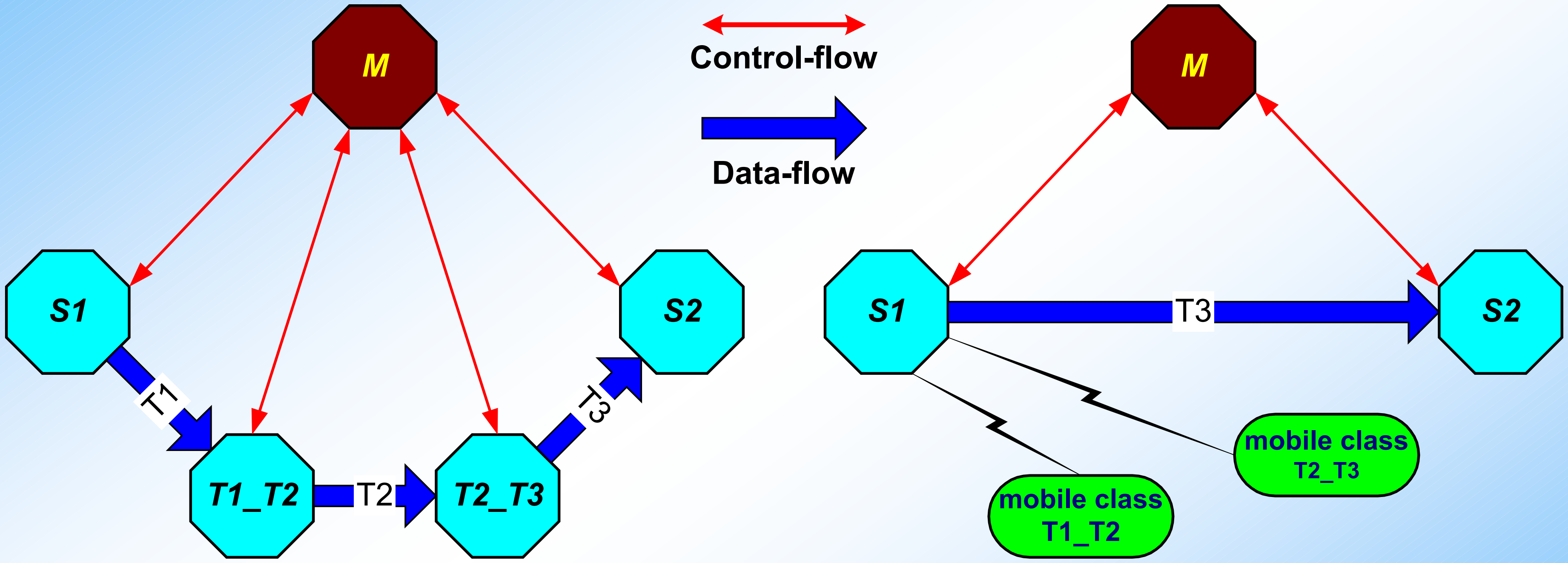
Usage of Mobile Class

- Arithmetic operation
- Relational operation
- Data aggregation and abstraction
- Type conversion

```
/* 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

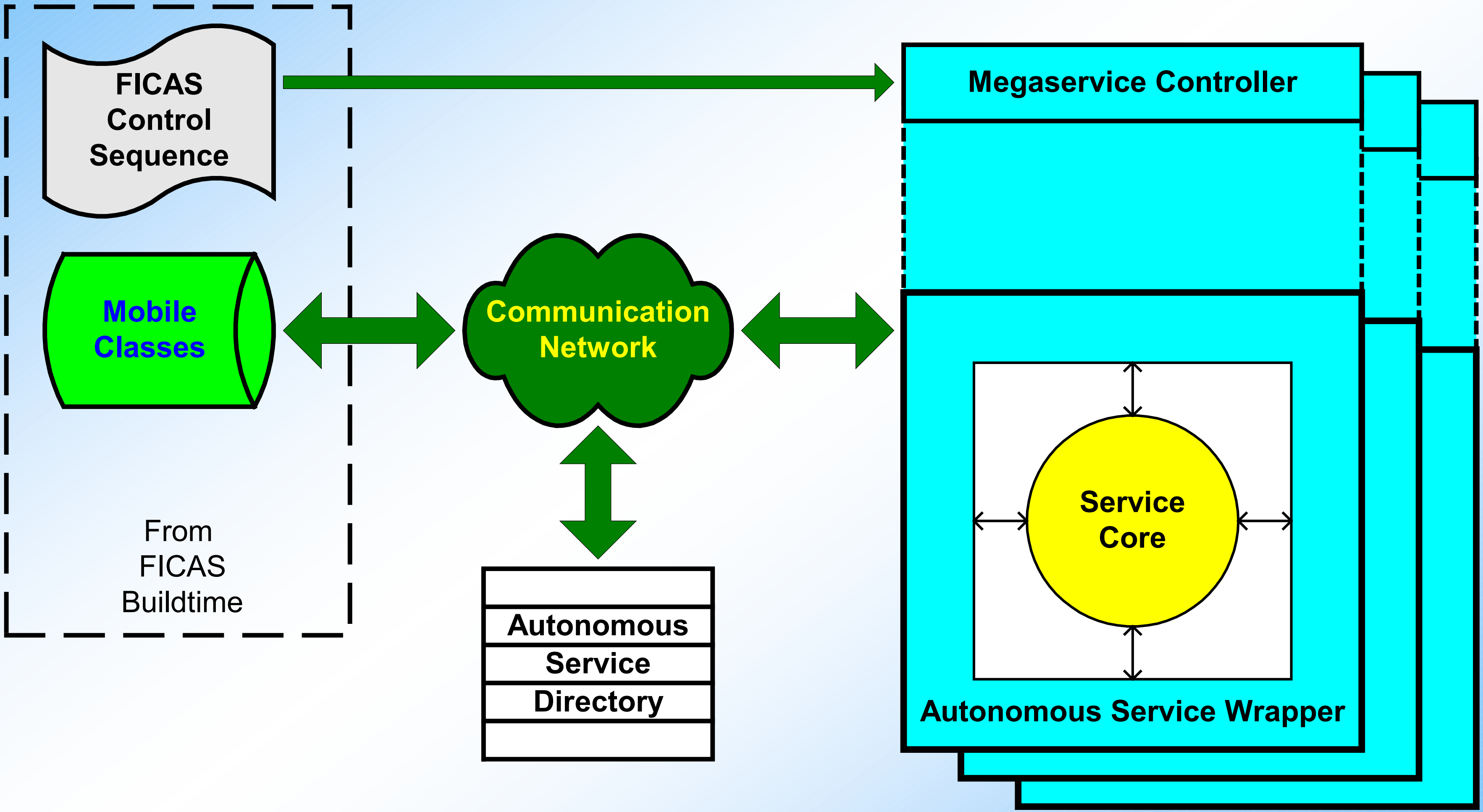


(a) Type Brokers

(b) Type Mediation Mobile Classes

Runtime Environment

Architecture of Runtime Environment



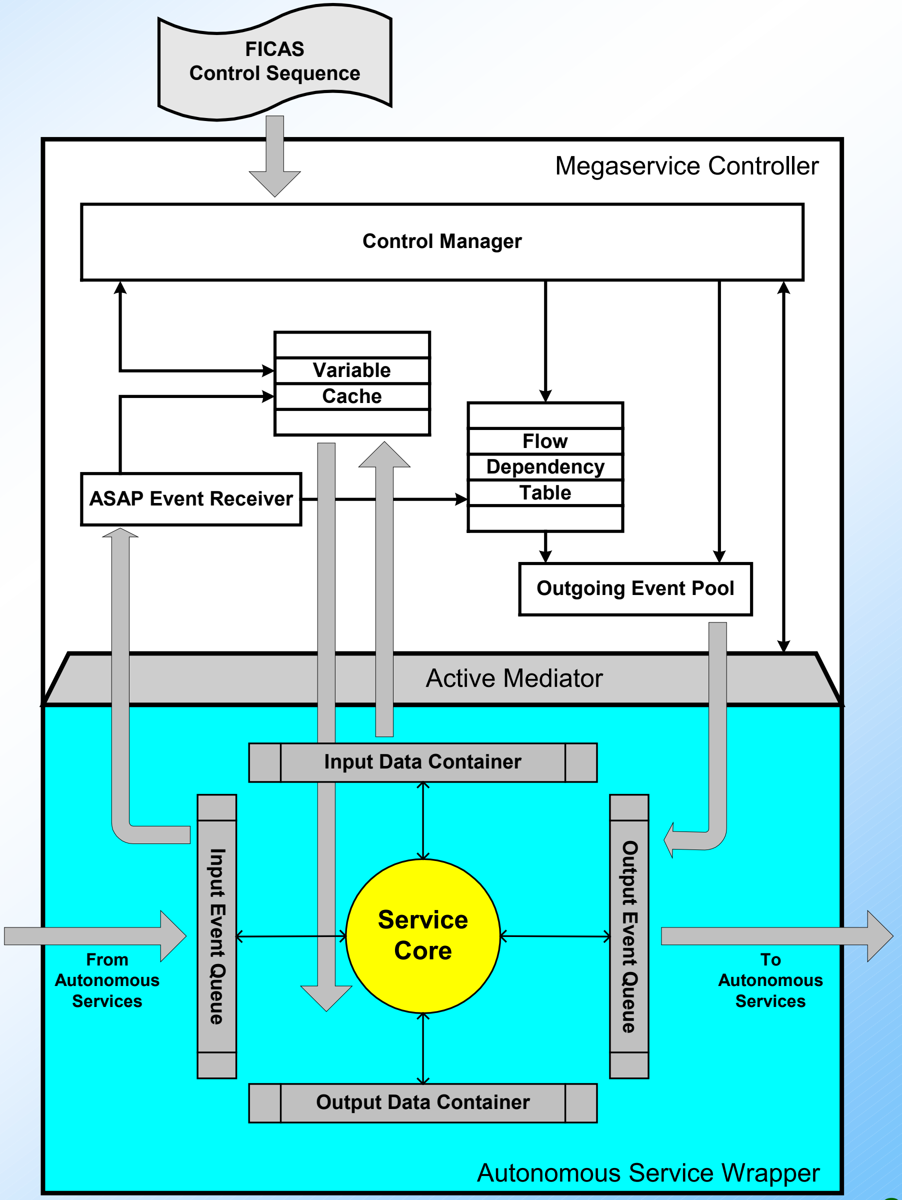
Megaservice Controller

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>

...
```

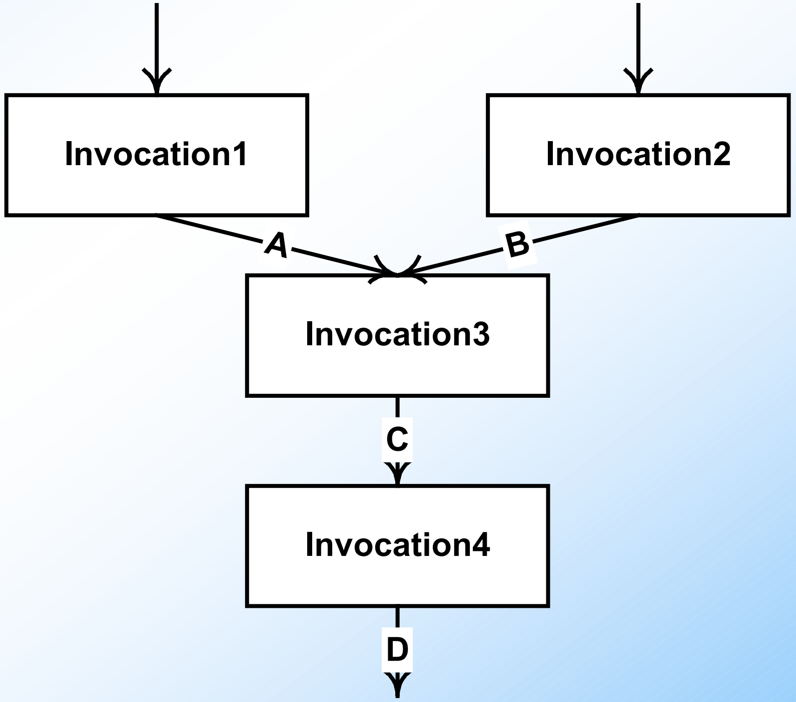


Extract Data Dependencies from Megaservice

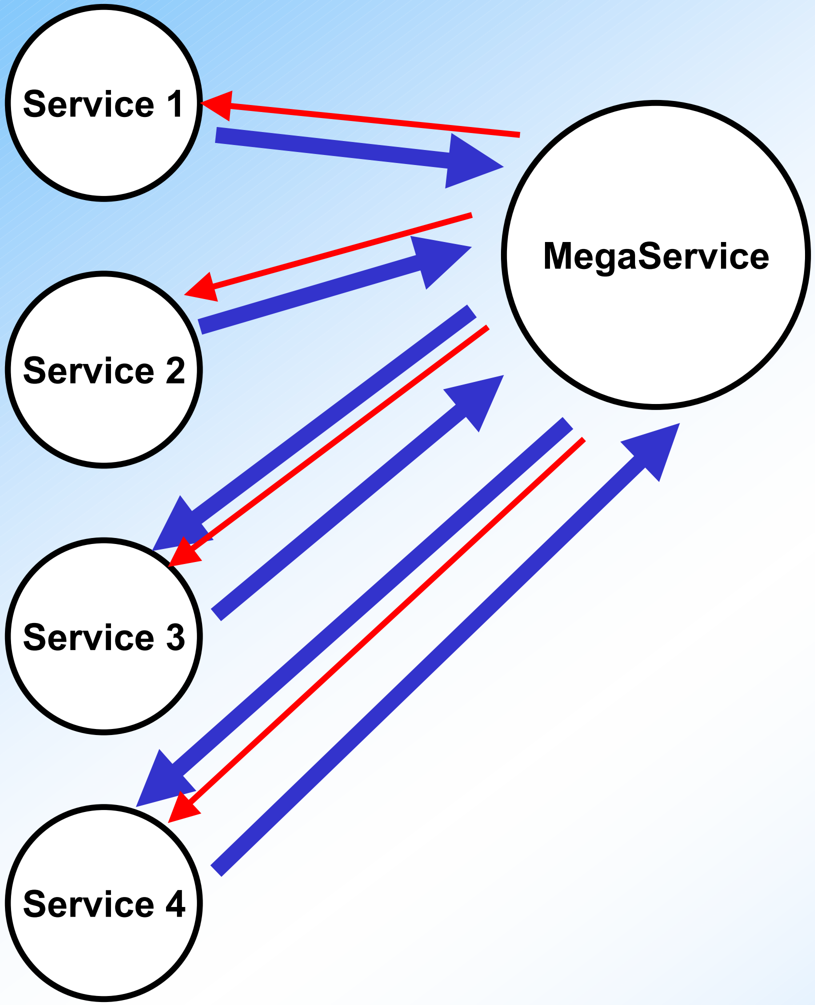
```
Invocation1 = Service1.INVOKE();
Invocation2 = Service2.INVOKE();
A = Invocation1.EXTRACT();
B = Invocation2.EXTRACT();

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

Invocation4 = Service4.INVOKE(C)
D = Invocation4.EXTRACT();
```



Event Dependency Graph (1C1D)



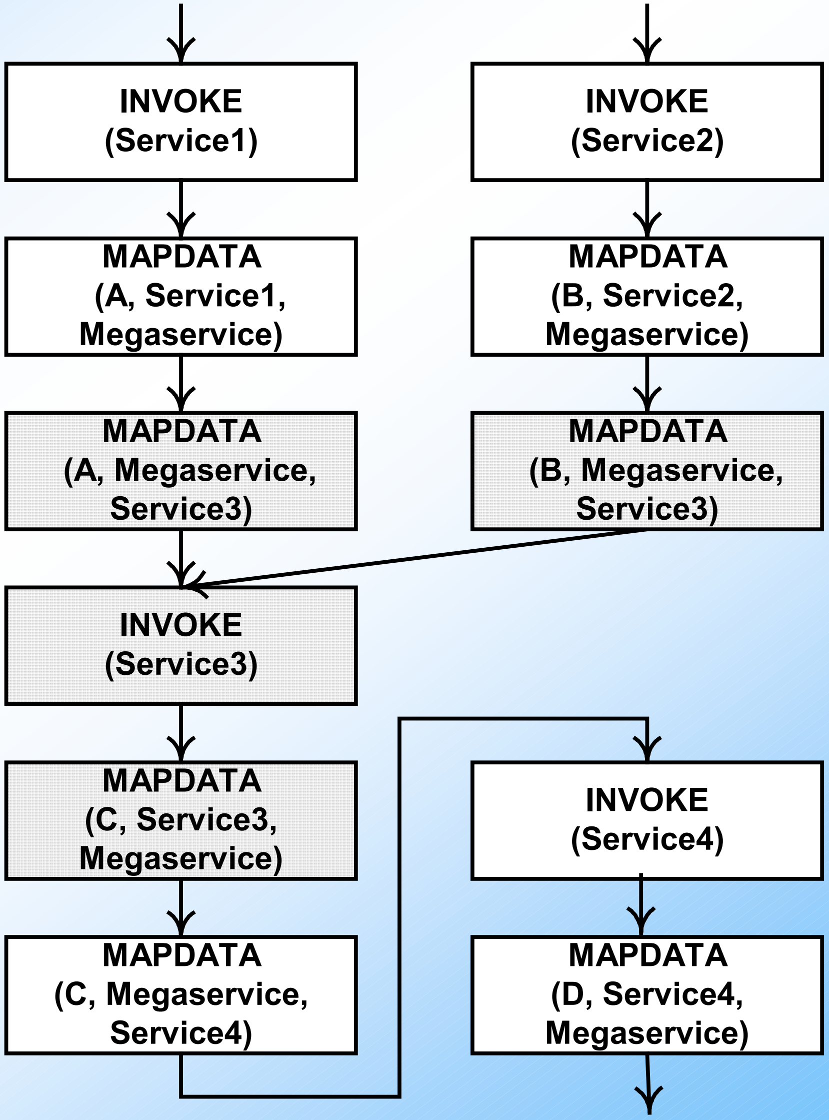
Service 1

Service 2

Service 3

Service 4

MegaService



INVOKE (Service1)

MAPDATA (A, Service1, Megaservice)

MAPDATA (A, Megaservice, Service3)

INVOKE (Service2)

MAPDATA (B, Service2, Megaservice)

MAPDATA (B, Megaservice, Service3)

INVOKE (Service3)

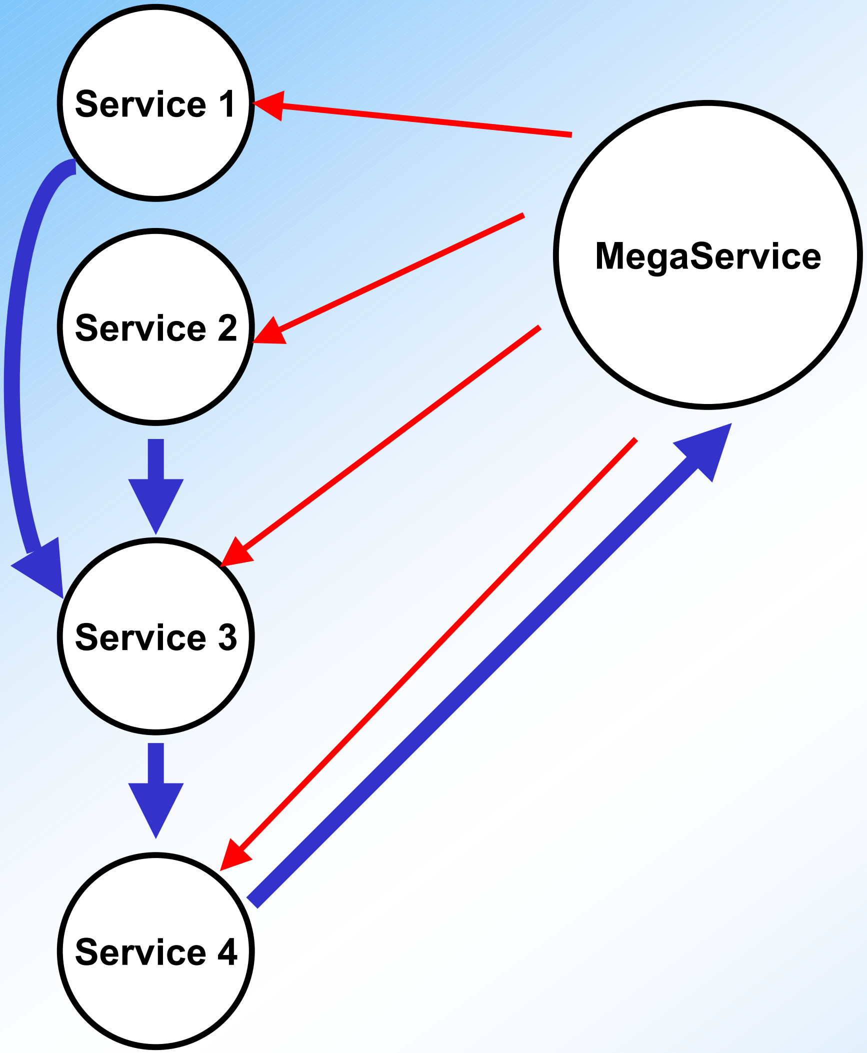
MAPDATA (C, Service3, Megaservice)

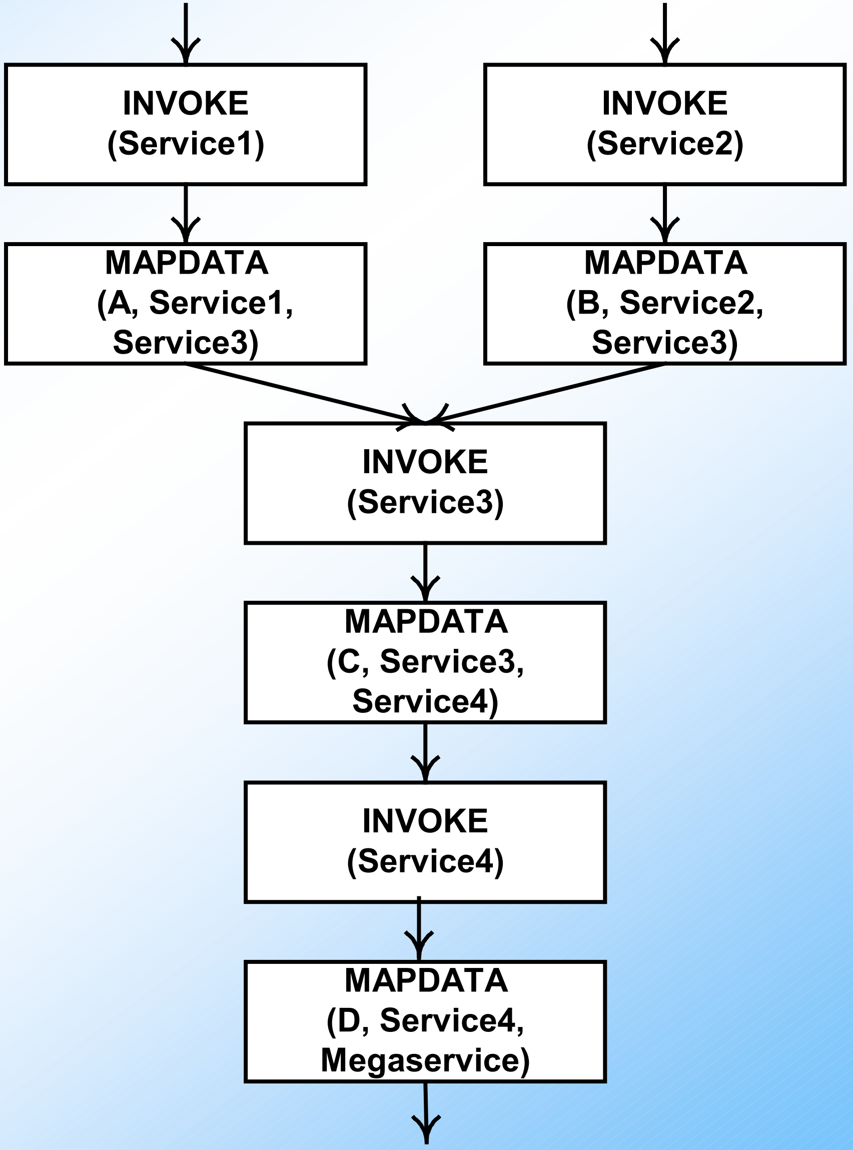
MAPDATA (C, Megaservice, Service4)

INVOKE (Service4)

MAPDATA (D, Service4, Megaservice)

Event Dependency Graph (1CnD)



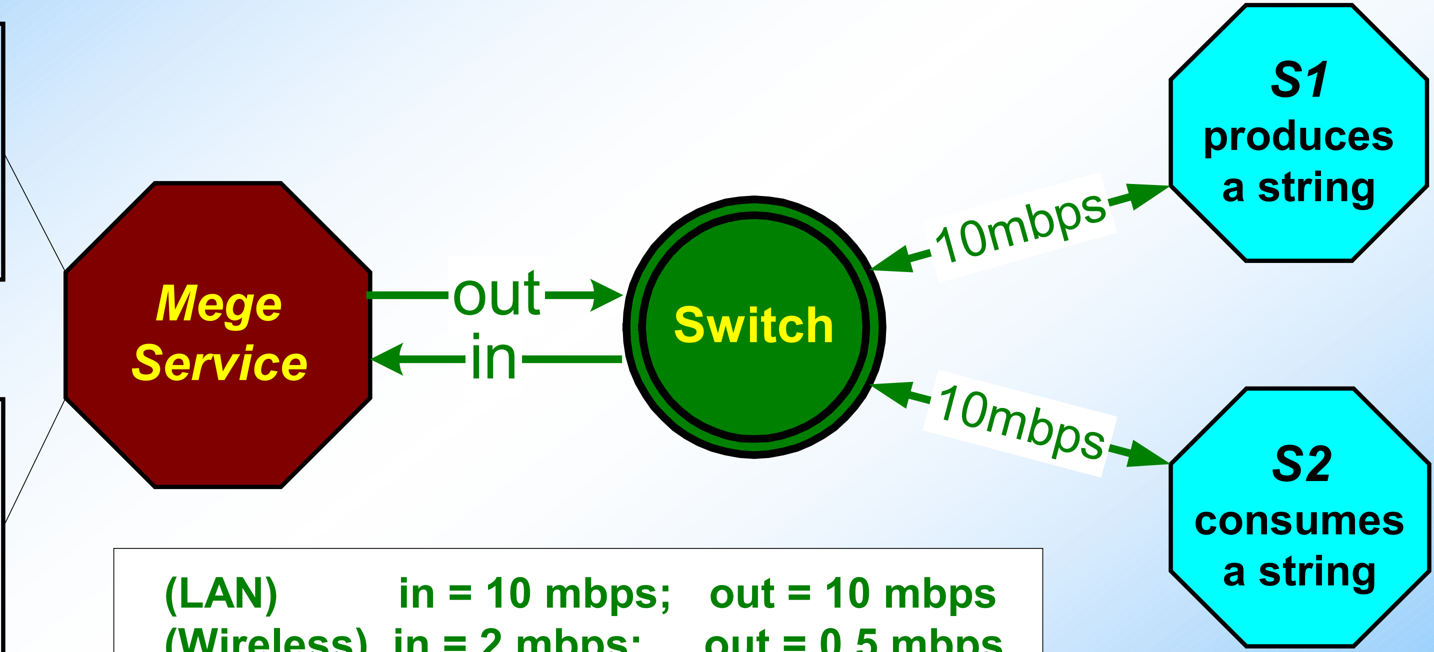


INVOKE (Service1)
INVOKE (Service2)
MAPDATA (A, Service1, Service3)
MAPDATA (B, Service2, Service3)
INVOKE (Service3)
MAPDATA (C, Service3, Service4)
INVOKE (Service4)
MAPDATA (D, Service4, Megaservice)

Performance Evaluation – SOAP vs. FICAS

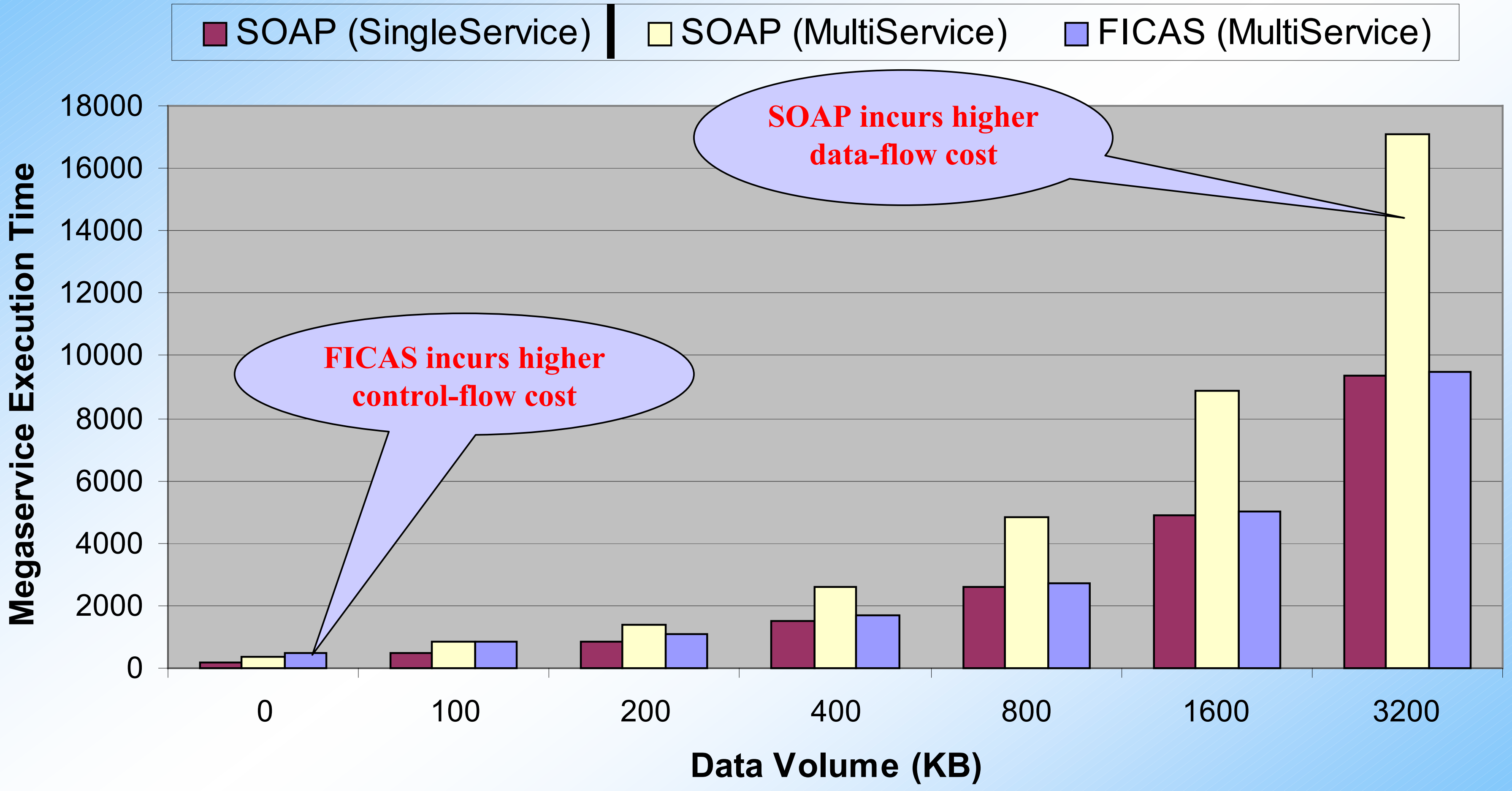
```
MultiService
{
    a = S1(size)
    S2(a)
}
```

```
SingleService
{
    a = S1(size)
}
```



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

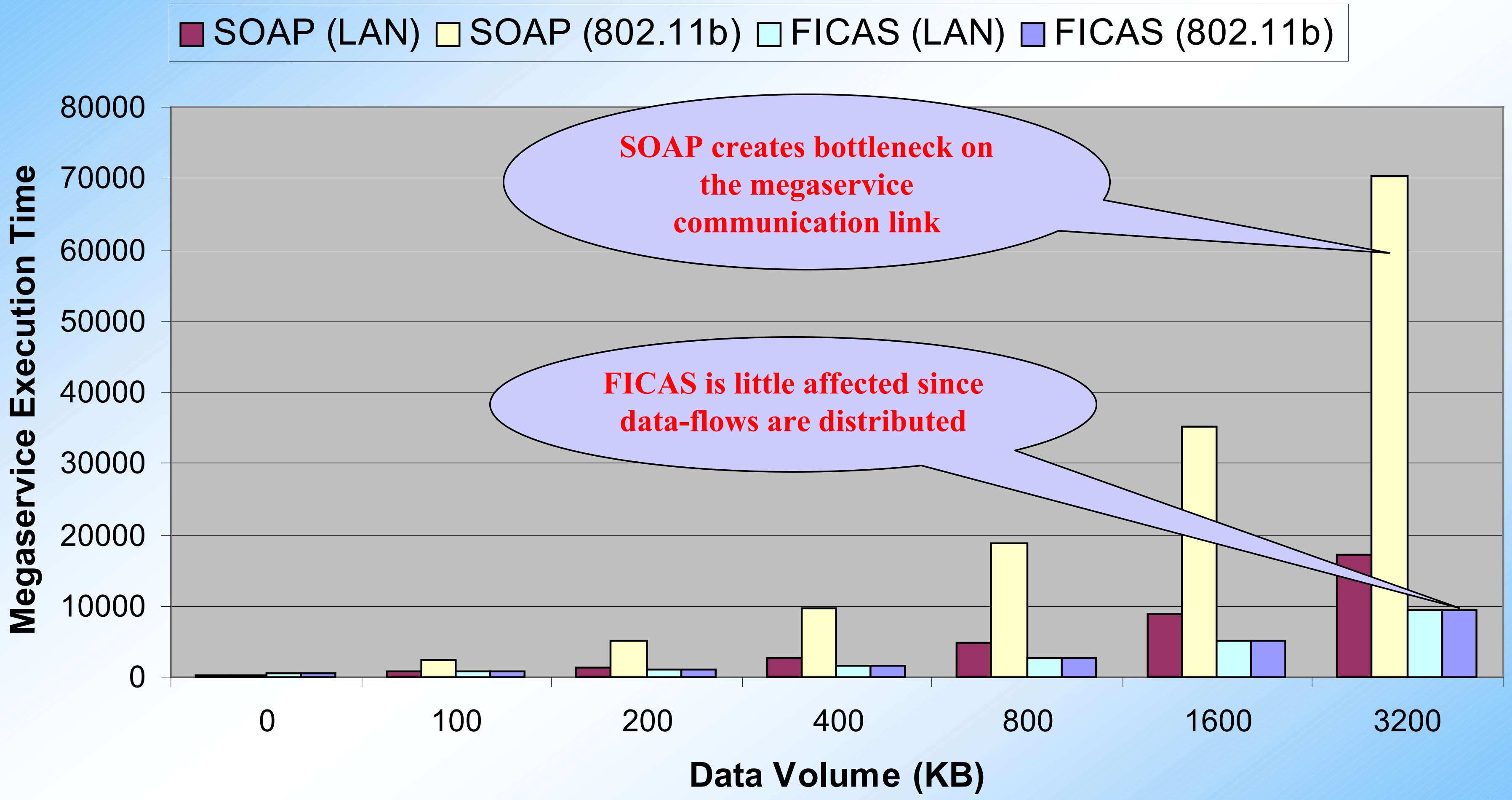
Performance in LAN Setting



SOAP incurs higher data-flow cost

FICAS incurs higher control-flow cost

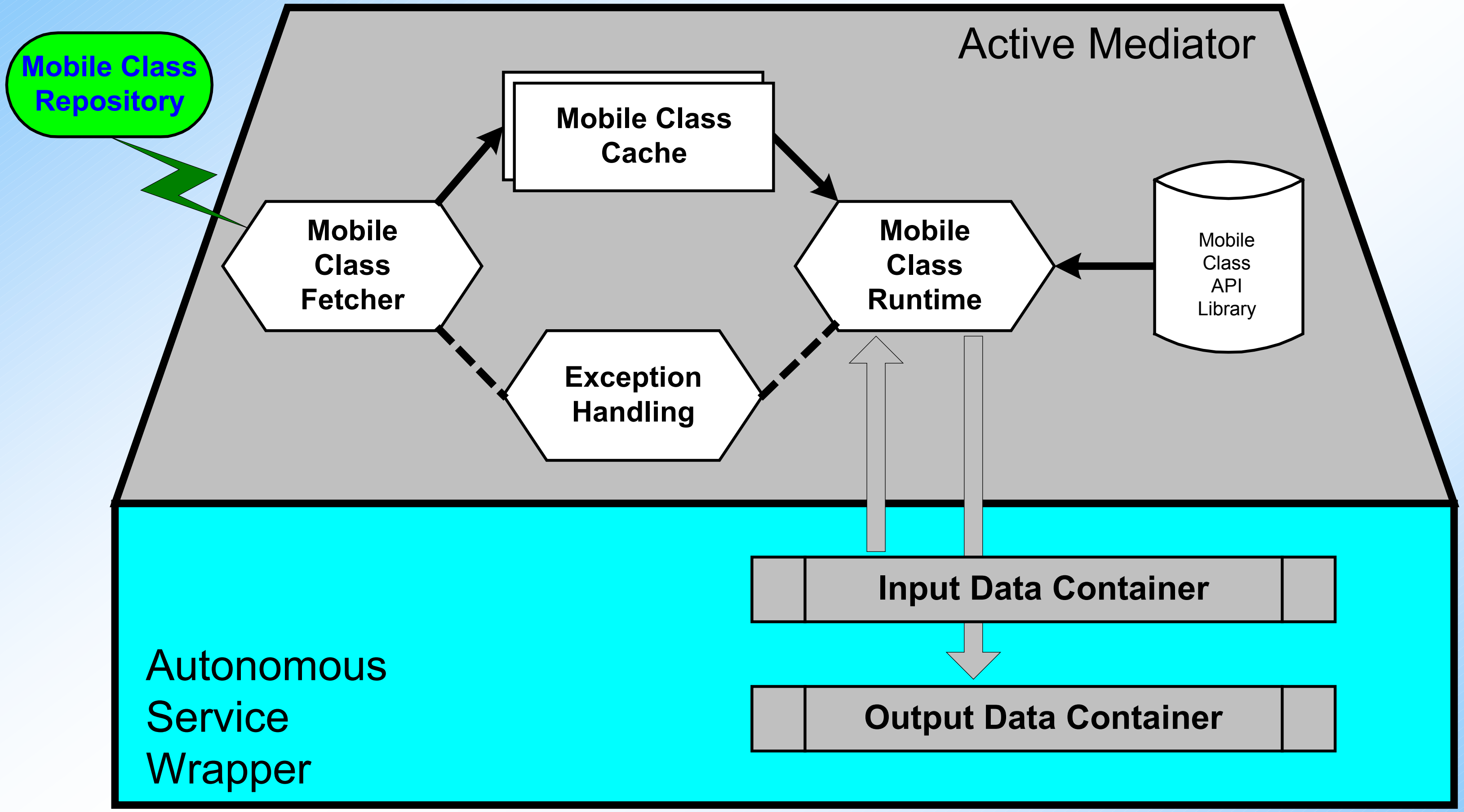
Performance in Wireless Setting



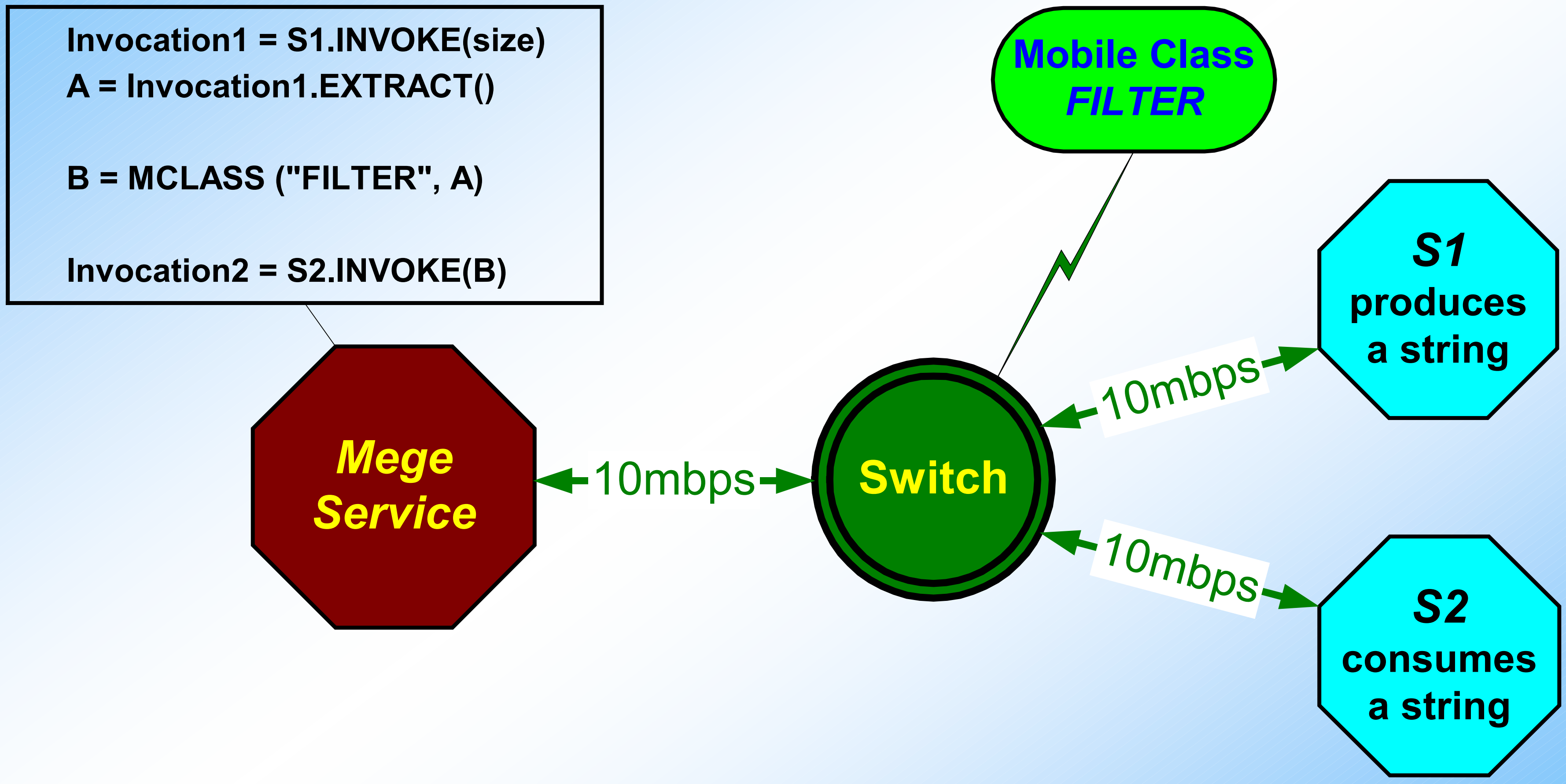
SOAP creates bottleneck on the megaservice communication link

FICAS is little affected since data-flows are distributed

Active Mediator



Example Megaservice Utilizing a Mobile Class

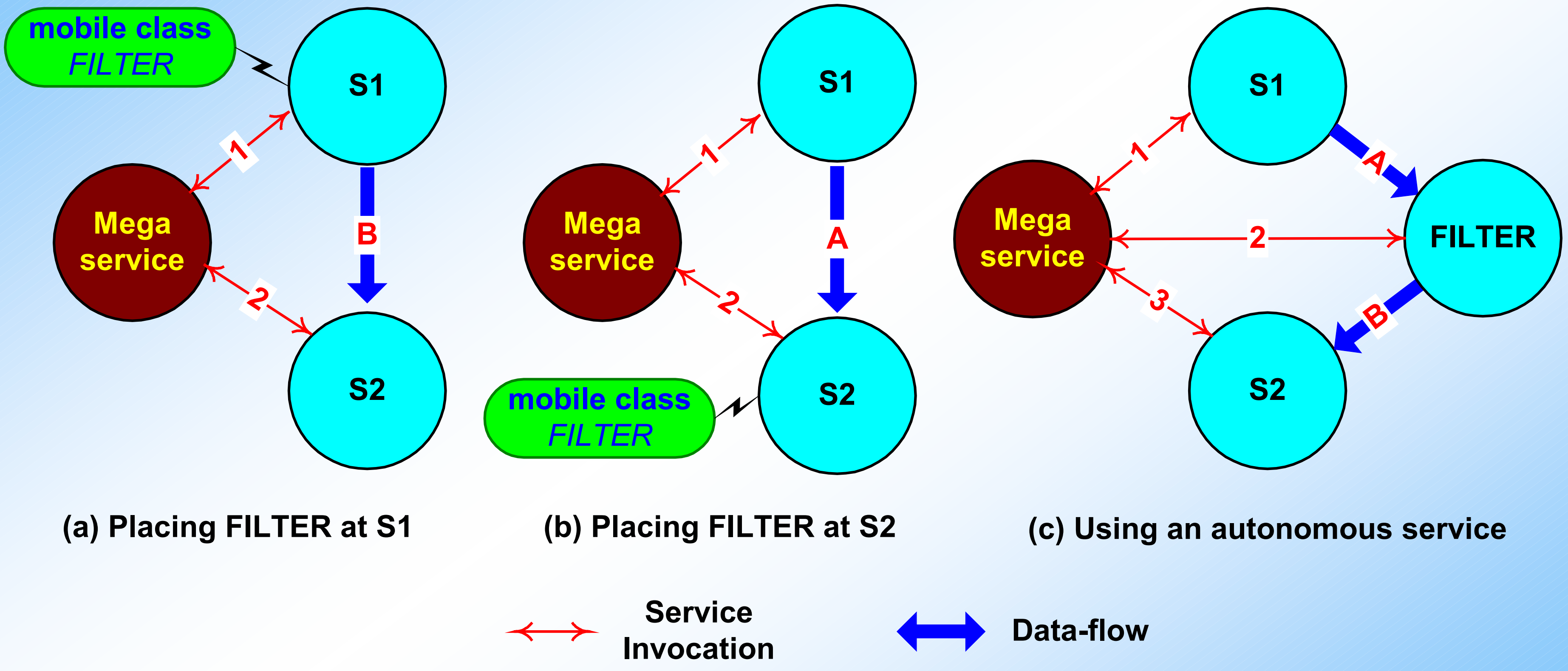


```
Invocation1 = S1.INVOKE(size)
A = Invocation1.EXTRACT()

B = MCLASS ("FILTER", A)

Invocation2 = S2.INVOKE(B)
```

Placement of Mobile Class

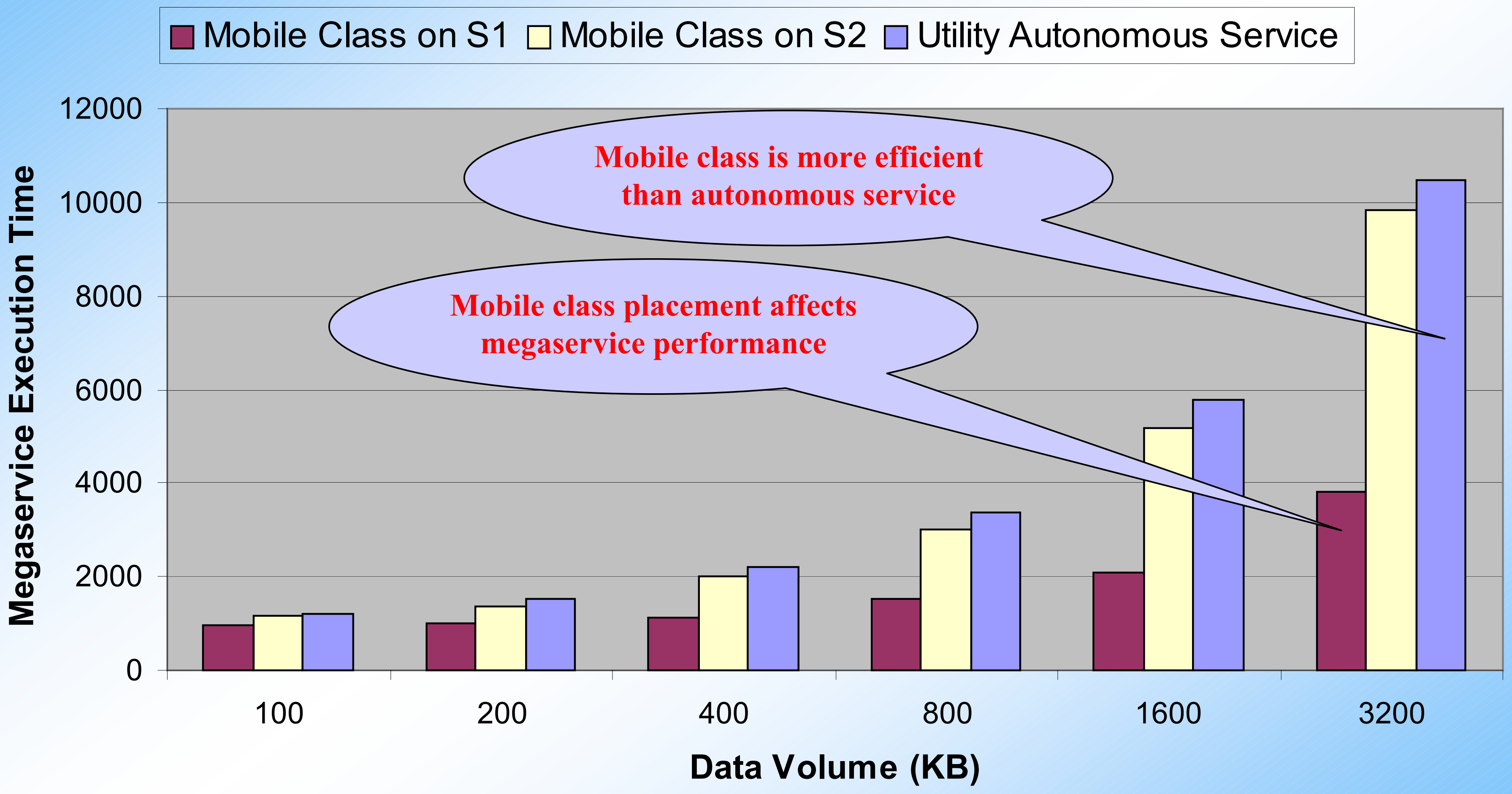


(a) Placing FILTER at S1

(b) Placing FILTER at S2

(c) Using an autonomous service

Performance Comparison for Mobile Class

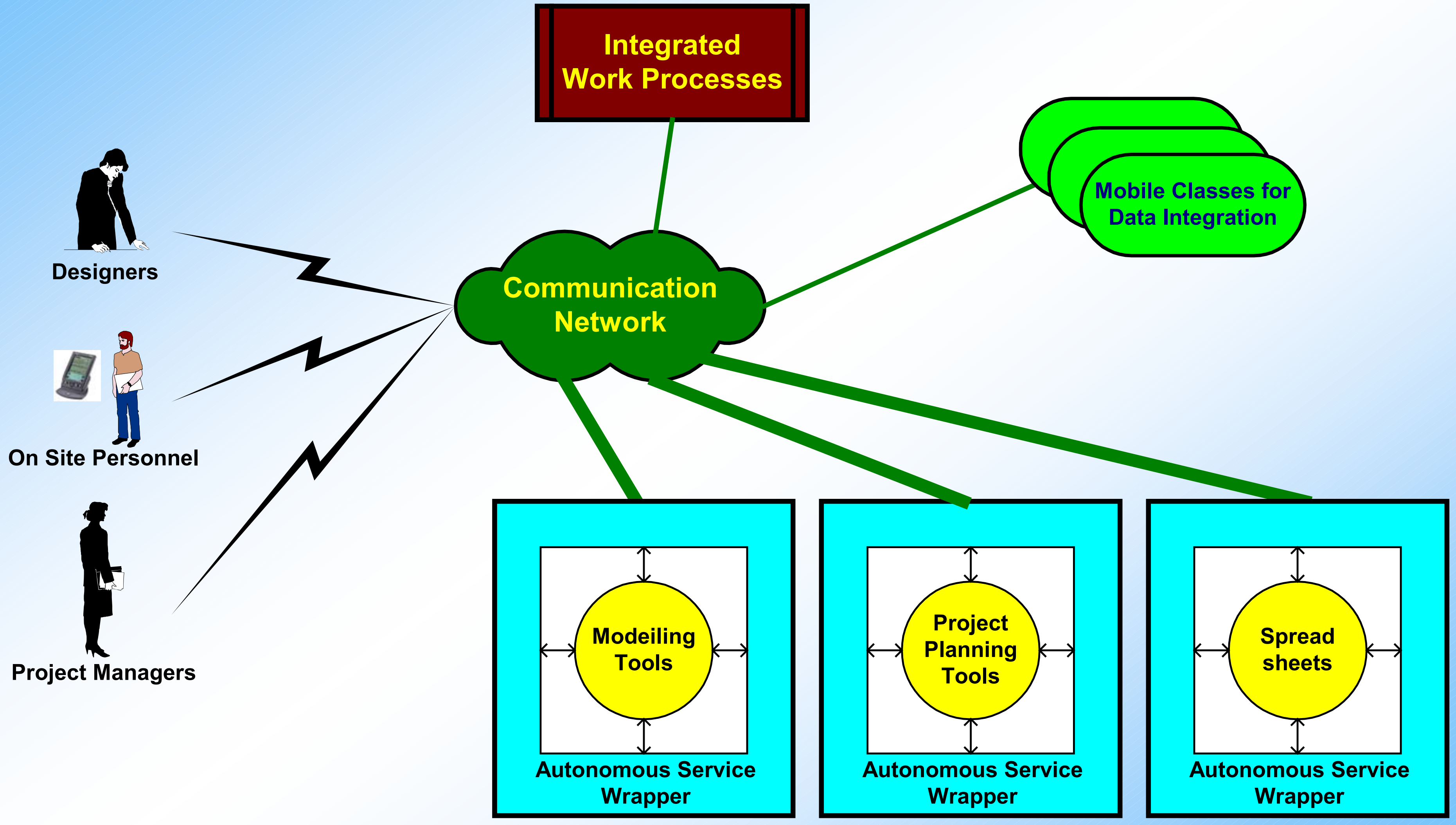


Mobile class is more efficient than autonomous service

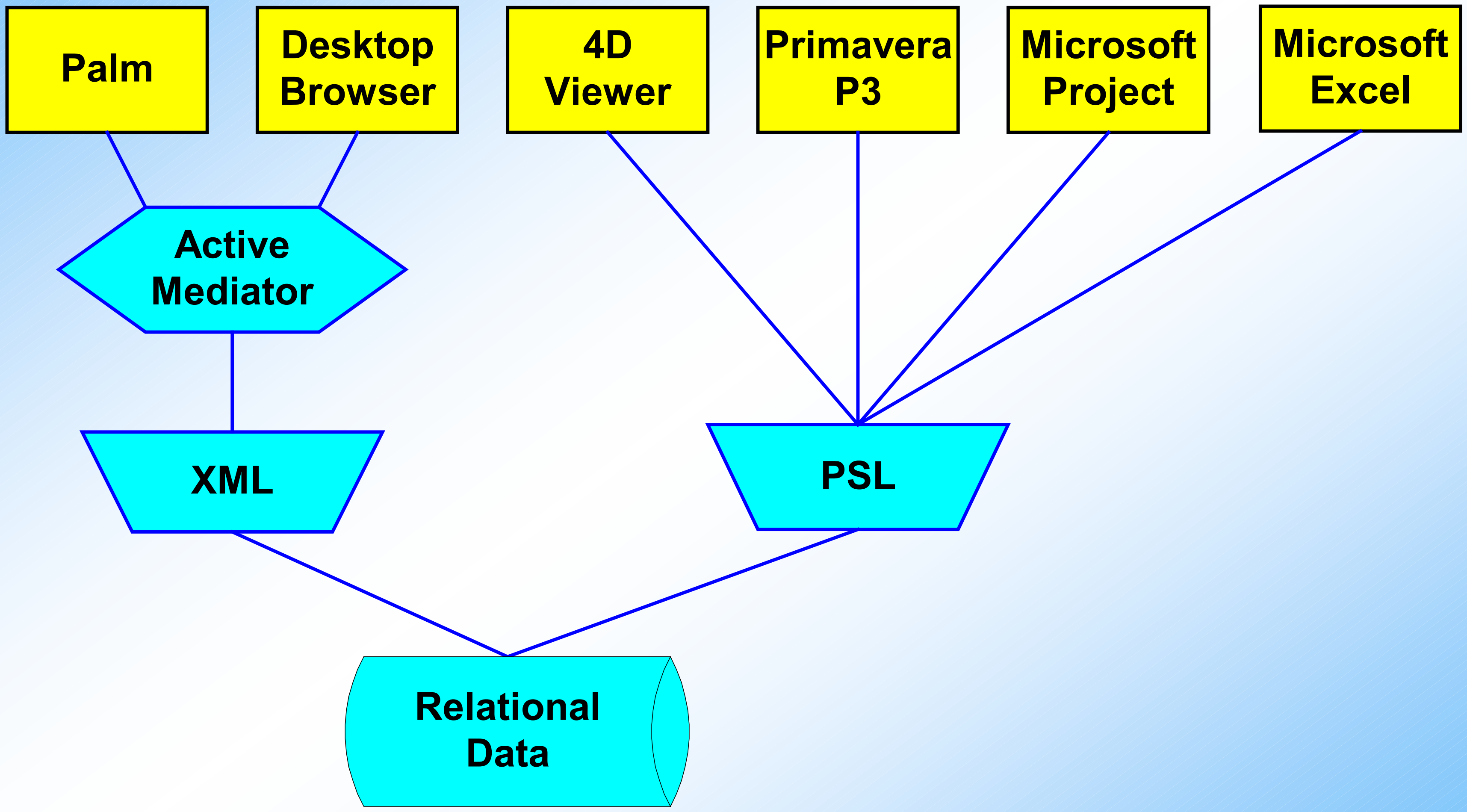
Mobile class placement affects megaservice performance

Infrastructure for Engineering Services

An Integrated Service Environment

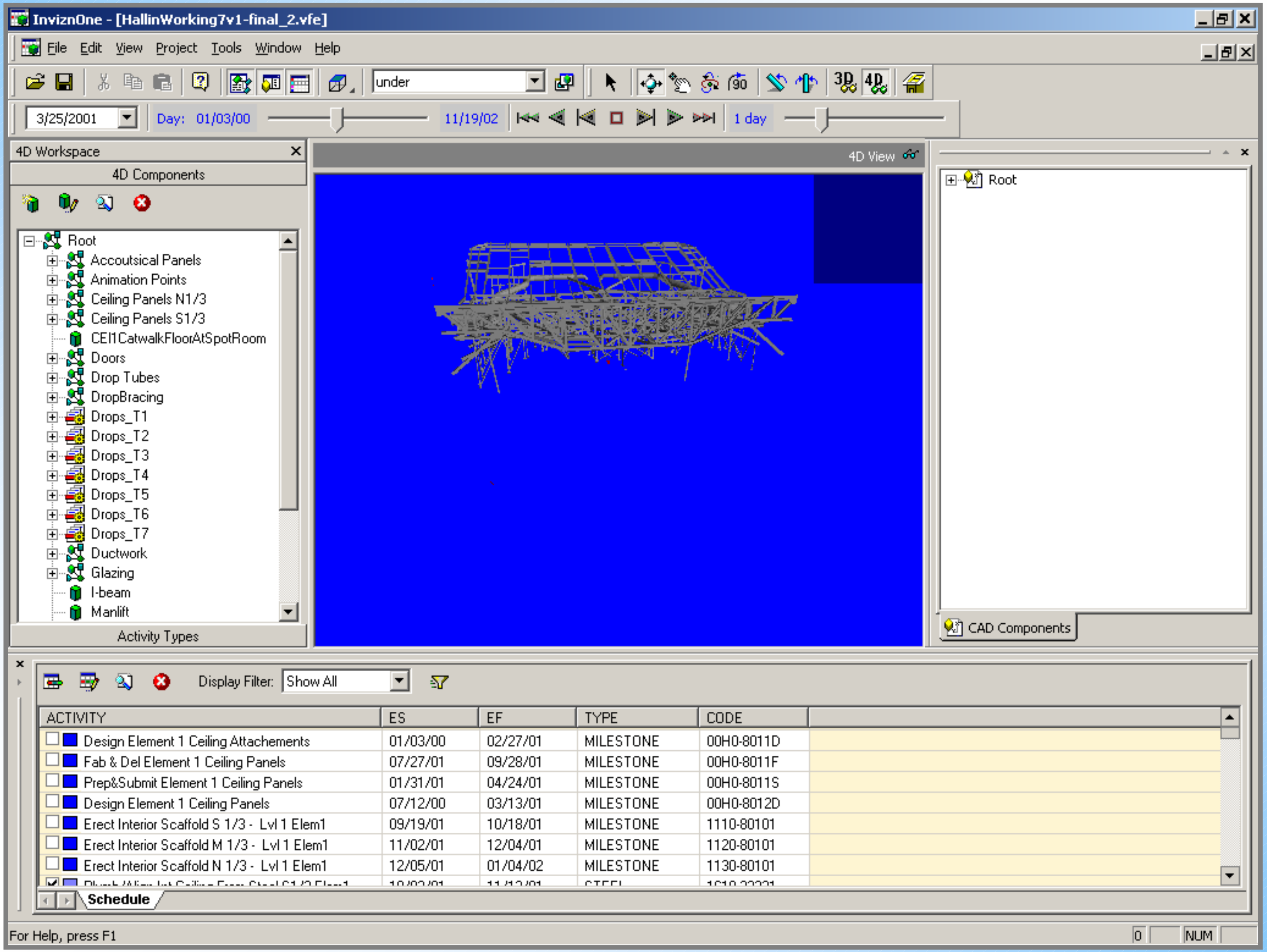

Integrated Work Processes
Mobile Classes for Data Integration
Designers
Communication Network
On Site Personnel
Project Managers
Modeiling Tools
Autonomous Service Wrapper
Project Planning Tools
Autonomous Service Wrapper
Spread sheets
Autonomous Service Wrapper

Data Mediation Among the Tools



Related work by Jim Cheng at Engineering Informatics Group, Stanford University

Review Design in 4D Viewer



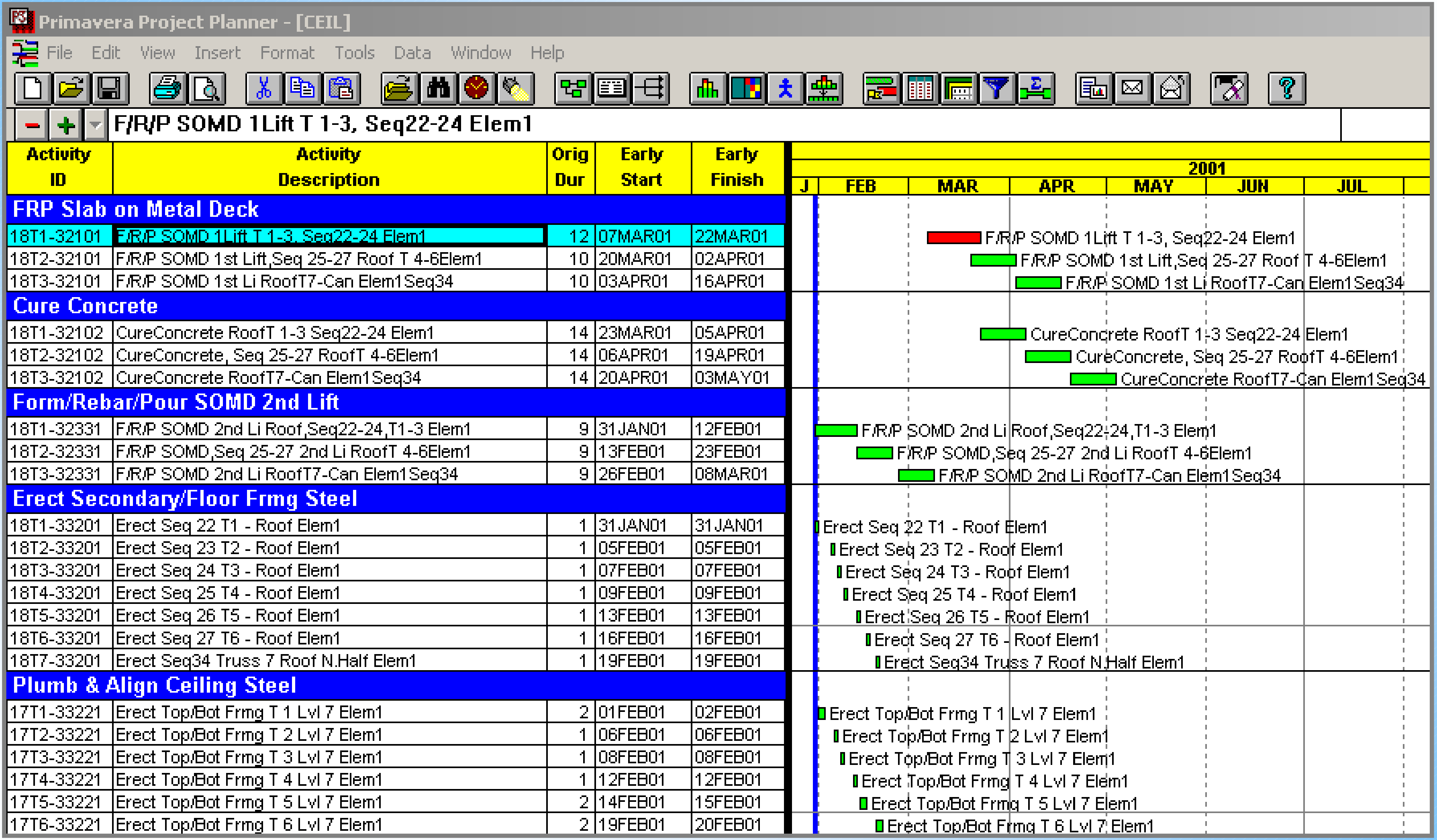
- Root
  - Accoutsical Panels
  - Animation Points
  - Ceiling Panels N1/3
  - Ceiling Panels S1/3
  - CEI1CatwalkFloorAtSpotRoom
  - Doors
  - Drop Tubes
  - DropBracing
  - Drops_T1
  - Drops_T2
  - Drops_T3
  - Drops_T4
  - Drops_T5
  - Drops_T6
  - Drops_T7
  - Ductwork
  - Glazing
  - I-beam
  - Manlift

Display Filter: Show All

ACTIVITY	ES	EF	TYPE	CODE
□ 🟦 Design Element 1 Ceiling Attachements	01/03/00	02/27/01	MILESTONE	00H0-8011D
□ 🟦 Fab & Del Element 1 Ceiling Panels	07/27/01	09/28/01	MILESTONE	00H0-8011F
□ 🟦 Prep&Submit Element 1 Ceiling Panels	01/31/01	04/24/01	MILESTONE	00H0-8011S
□ 🟦 Design Element 1 Ceiling Panels	07/12/00	03/13/01	MILESTONE	00H0-8012D
□ 🟦 Erect Interior Scaffold S 1/3 - Lvl 1 Elem1	09/19/01	10/18/01	MILESTONE	1110-80101
□ 🟦 Erect Interior Scaffold M 1/3 - Lvl 1 Elem1	11/02/01	12/04/01	MILESTONE	1120-80101
□ 🟦 Erect Interior Scaffold N 1/3 - Lvl 1 Elem1	12/05/01	01/04/02	MILESTONE	1130-80101
☑ 🟦 Plumb/Align Int Ceiling Fram Steel S1/3 Elem1	10/02/01	11/13/01	STEEL	1610-22221

For Help, press F1

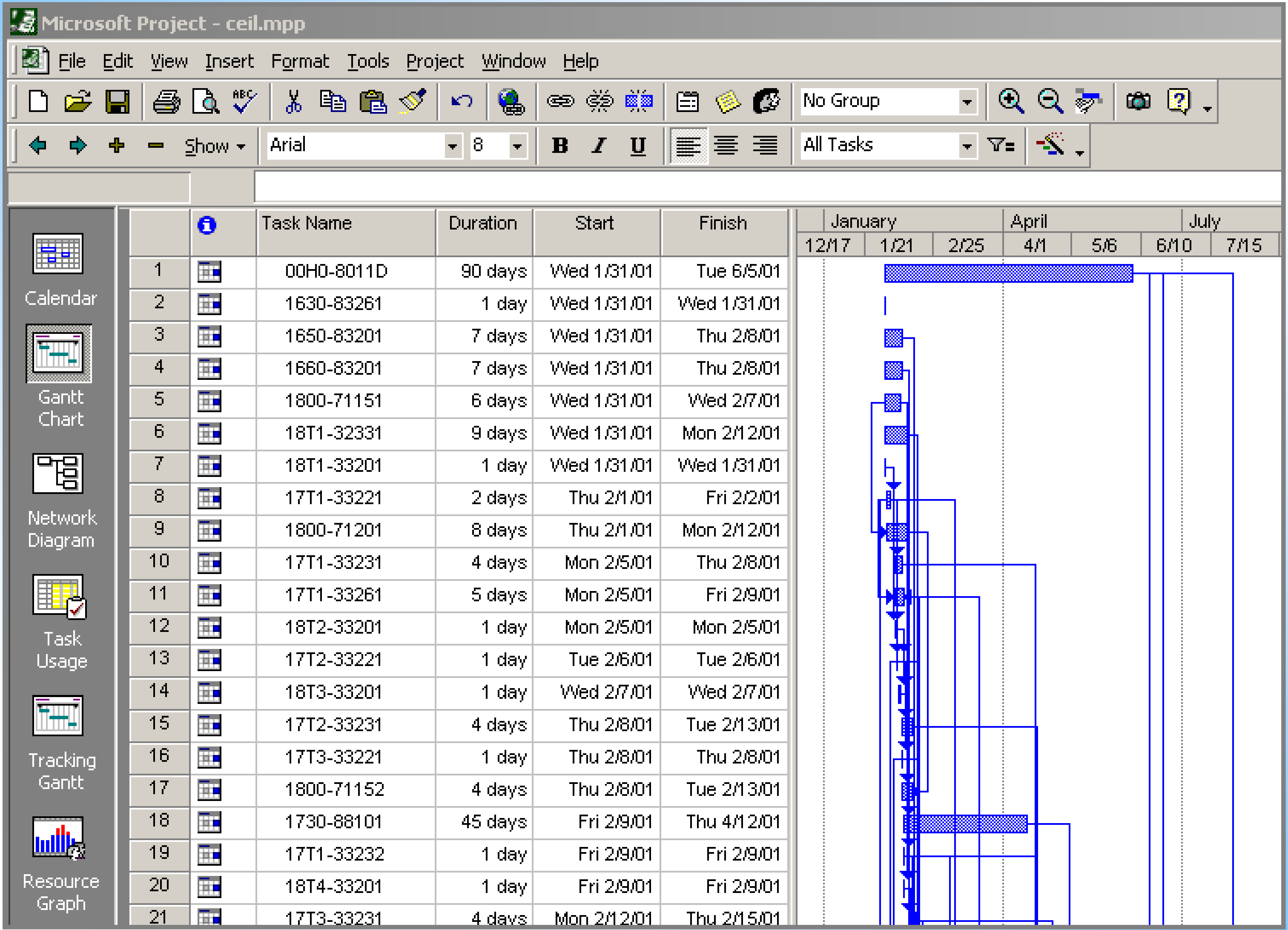
Review Schedule in Primavera



F/R/P SOMD 1Lift T 1-3, Seq22-24 Elem1

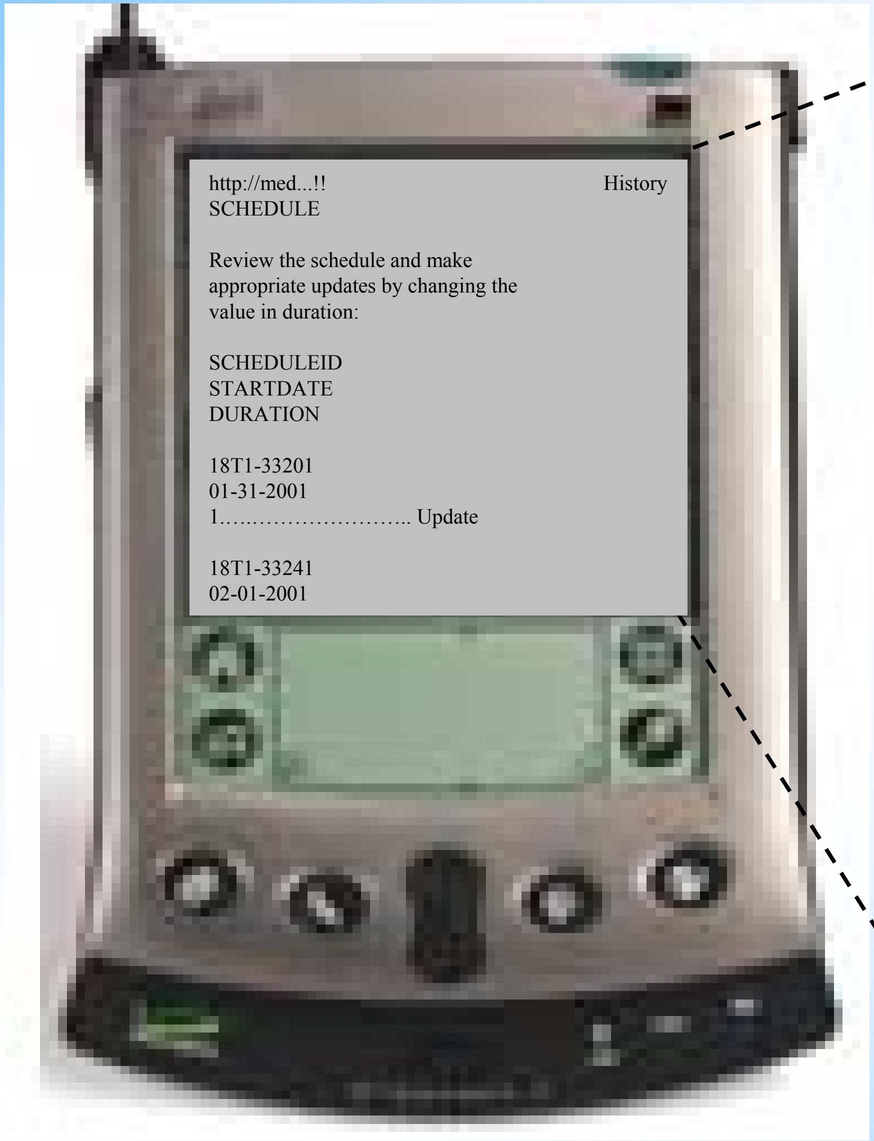
Activity ID	Activity Description	Orig Dur	Early Start	Early Finish
FRP Slab on Metal Deck				
18T1-32101	F/R/P SOMD 1Lift T 1-3, Seq22-24 Elem1	12	07MAR01	22MAR01
18T2-32101	F/R/P SOMD 1st Lift,Seq 25-27 Roof T 4-6Elem1	10	20MAR01	02APR01
18T3-32101	F/R/P SOMD 1st Li RoofT7-Can Elem1Seq34	10	03APR01	16APR01
Cure Concrete				
18T1-32102	CureConcrete RoofT 1-3 Seq22-24 Elem1	14	23MAR01	05APR01
18T2-32102	CureConcrete, Seq 25-27 RoofT 4-6Elem1	14	06APR01	19APR01
18T3-32102	CureConcrete RoofT7-Can Elem1Seq34	14	20APR01	03MAY01
Form/Rebar/Pour SOMD 2nd Lift				
18T1-32331	F/R/P SOMD 2nd Li Roof,Seq22-24,T1-3 Elem1	9	31JAN01	12FEB01
18T2-32331	F/R/P SOMD,Seq 25-27 2nd Li RoofT 4-6Elem1	9	13FEB01	23FEB01
18T3-32331	F/R/P SOMD 2nd Li RoofT7-Can Elem1Seq34	9	26FEB01	08MAR01
Erect Secondary/Floor Frmg Steel				
18T1-33201	Erect Seq 22 T1 - Roof Elem1	1	31JAN01	31JAN01
18T2-33201	Erect Seq 23 T2 - Roof Elem1	1	05FEB01	05FEB01
18T3-33201	Erect Seq 24 T3 - Roof Elem1	1	07FEB01	07FEB01
18T4-33201	Erect Seq 25 T4 - Roof Elem1	1	09FEB01	09FEB01
18T5-33201	Erect Seq 26 T5 - Roof Elem1	1	13FEB01	13FEB01
18T6-33201	Erect Seq 27 T6 - Roof Elem1	1	16FEB01	16FEB01
18T7-33201	Erect Seq34 Truss 7 Roof N.Half Elem1	1	19FEB01	19FEB01
Plumb & Align Ceiling Steel				
17T1-33221	Erect Top/Bot Frmg T 1 Lvl 7 Elem1	2	01FEB01	02FEB01
17T2-33221	Erect Top/Bot Frmg T 2 Lvl 7 Elem1	1	06FEB01	06FEB01
17T3-33221	Erect Top/Bot Frmg T 3 Lvl 7 Elem1	1	08FEB01	08FEB01
17T4-33221	Erect Top/Bot Frmg T 4 Lvl 7 Elem1	1	12FEB01	12FEB01
17T5-33221	Erect Top/Bot Frmg T 5 Lvl 7 Elem1	2	14FEB01	15FEB01
17T6-33221	Erect Top/Bot Frmg T 6 Lvl 7 Elem1	2	19FEB01	20FEB01

Review Schedule in Microsoft Project



	ℹ	Task Name	Duration	Start	Finish
1	▦	00H0-8011D	90 days	Wed 1/31/01	Tue 6/5/01
2	▦	1630-83261	1 day	Wed 1/31/01	Wed 1/31/01
3	▦	1650-83201	7 days	Wed 1/31/01	Thu 2/8/01
4	▦	1660-83201	7 days	Wed 1/31/01	Thu 2/8/01
5	▦	1800-71151	6 days	Wed 1/31/01	Wed 2/7/01
6	▦	18T1-32331	9 days	Wed 1/31/01	Mon 2/12/01
7	▦	18T1-33201	1 day	Wed 1/31/01	Wed 1/31/01
8	▦	17T1-33221	2 days	Thu 2/1/01	Fri 2/2/01
9	▦	1800-71201	8 days	Thu 2/1/01	Mon 2/12/01
10	▦	17T1-33231	4 days	Mon 2/5/01	Thu 2/8/01
11	▦	17T1-33261	5 days	Mon 2/5/01	Fri 2/9/01
12	▦	18T2-33201	1 day	Mon 2/5/01	Mon 2/5/01
13	▦	17T2-33221	1 day	Tue 2/6/01	Tue 2/6/01
14	▦	18T3-33201	1 day	Wed 2/7/01	Wed 2/7/01
15	▦	17T2-33231	4 days	Thu 2/8/01	Tue 2/13/01
16	▦	17T3-33221	1 day	Thu 2/8/01	Thu 2/8/01
17	▦	1800-71152	4 days	Thu 2/8/01	Tue 2/13/01
18	▦	1730-88101	45 days	Fri 2/9/01	Thu 4/12/01
19	▦	17T1-33232	1 day	Fri 2/9/01	Fri 2/9/01
20	▦	18T4-33201	1 day	Fri 2/9/01	Fri 2/9/01
21	▦	17T3-33231	4 days	Mon 2/12/01	Thu 2/15/01

View Schedule on Site



http://med...!! History
SCHEDULE

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

SCHEDULEID
STARTDATE
DURATION

18T1-33201
01-31-2001
1……..…………………….. Update

18T1-33241
02-01-2001

http://med...!! History
SCHEDULE

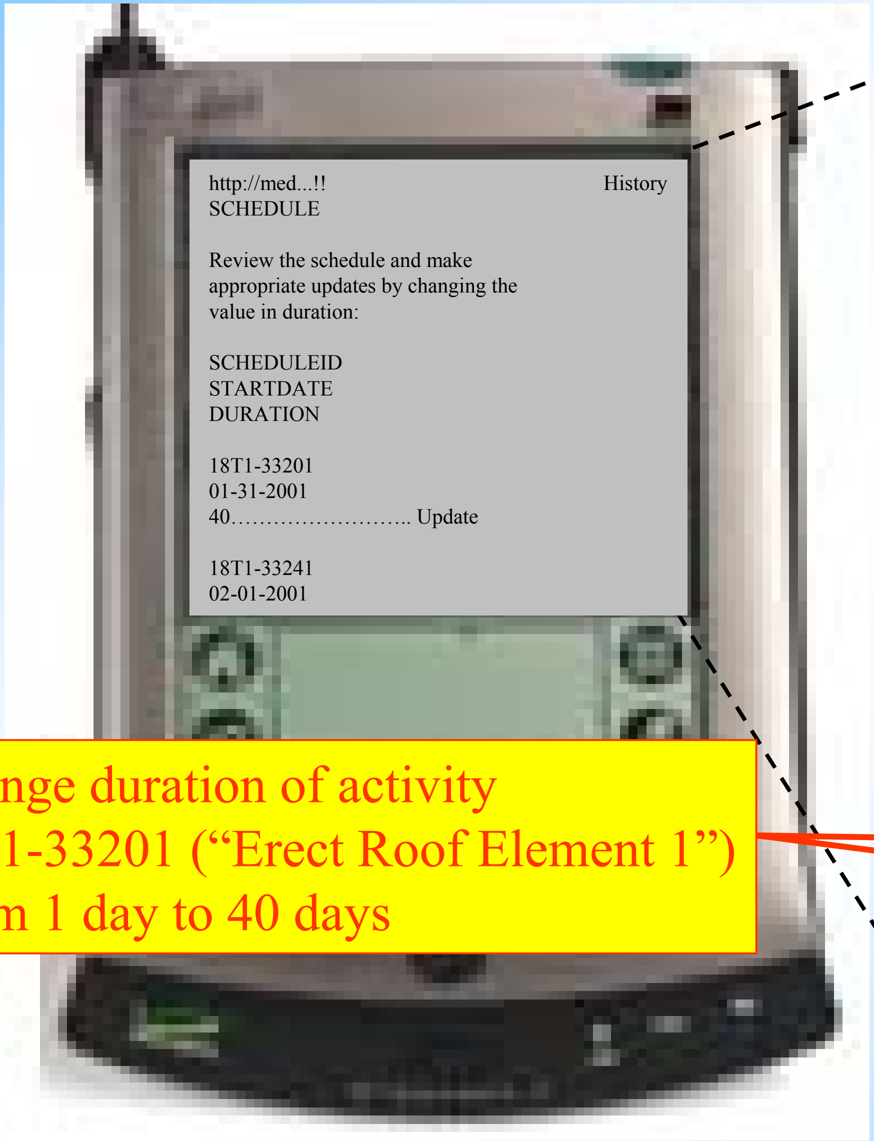
Review the schedule and make appropriate updates by changing the value in duration:

SCHEDULEID
STARTDATE
DURATION

18T1-33201
01-31-2001
1……..…………………….. Update

18T1-33241
02-01-2001

Modifying Schedule On-site



http://med...!! History
SCHEDULE

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

SCHEDULEID
STARTDATE
DURATION

18T1-33201
01-31-2001
40…………………….. Update

18T1-33241
02-01-2001

http://med...!! History
SCHEDULE

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

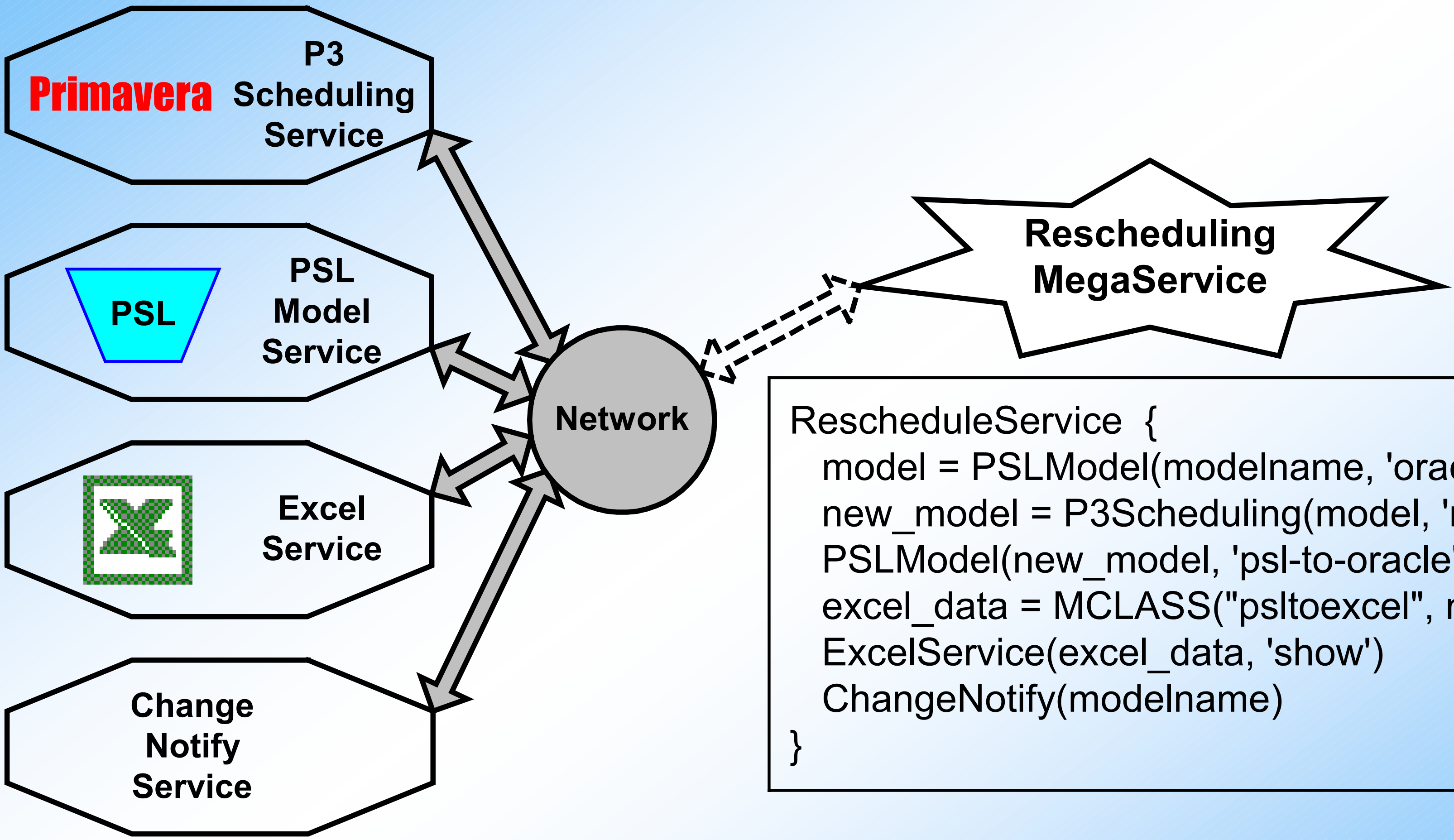
SCHEDULEID
STARTDATE
DURATION

18T1-33201
01-31-2001
40…………………….. Update

18T1-33241
02-01-2001

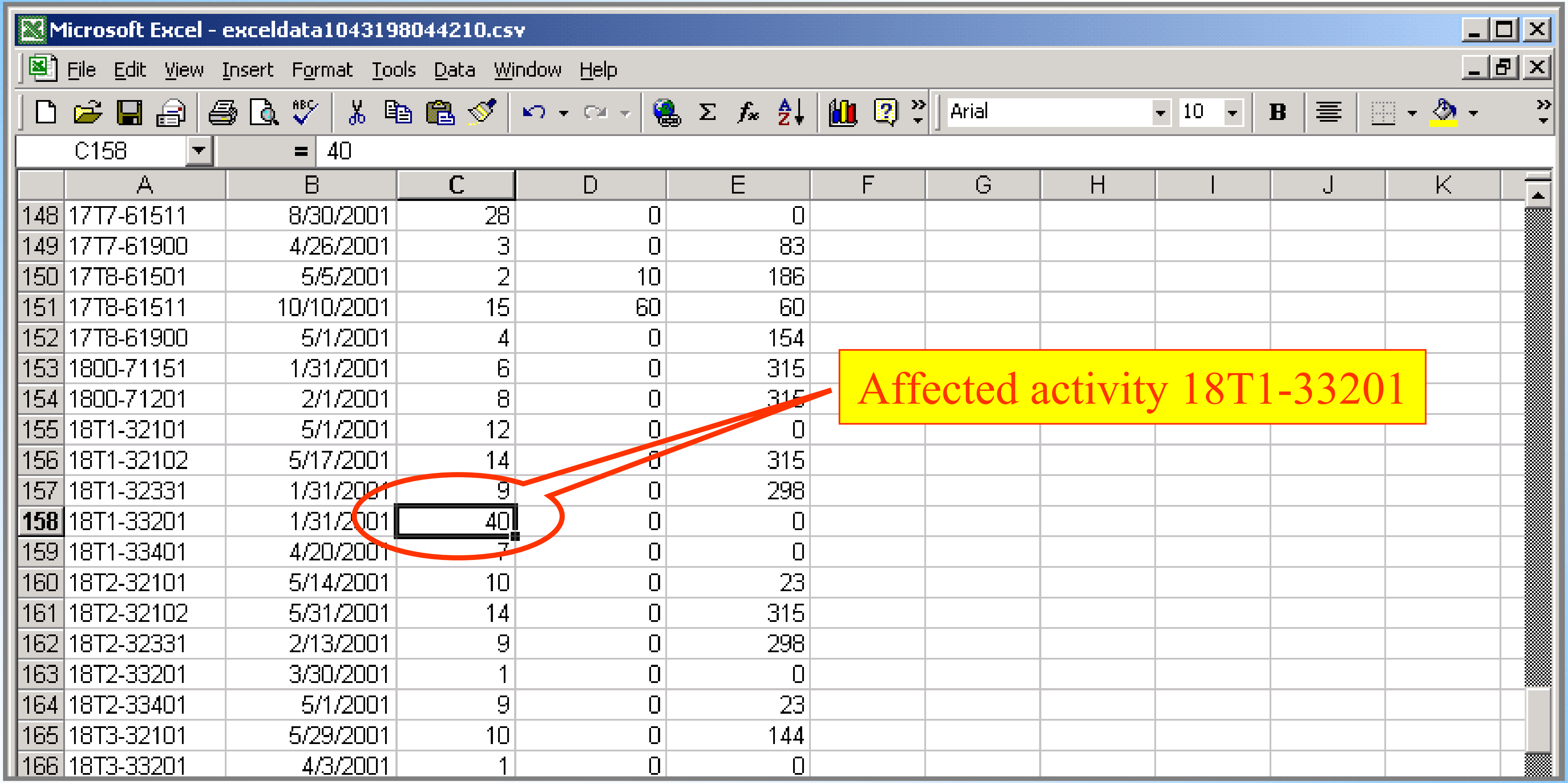
Change duration of activity 18T1-33201 (“Erect Roof Element 1”) From 1 day to 40 days

Invoke 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

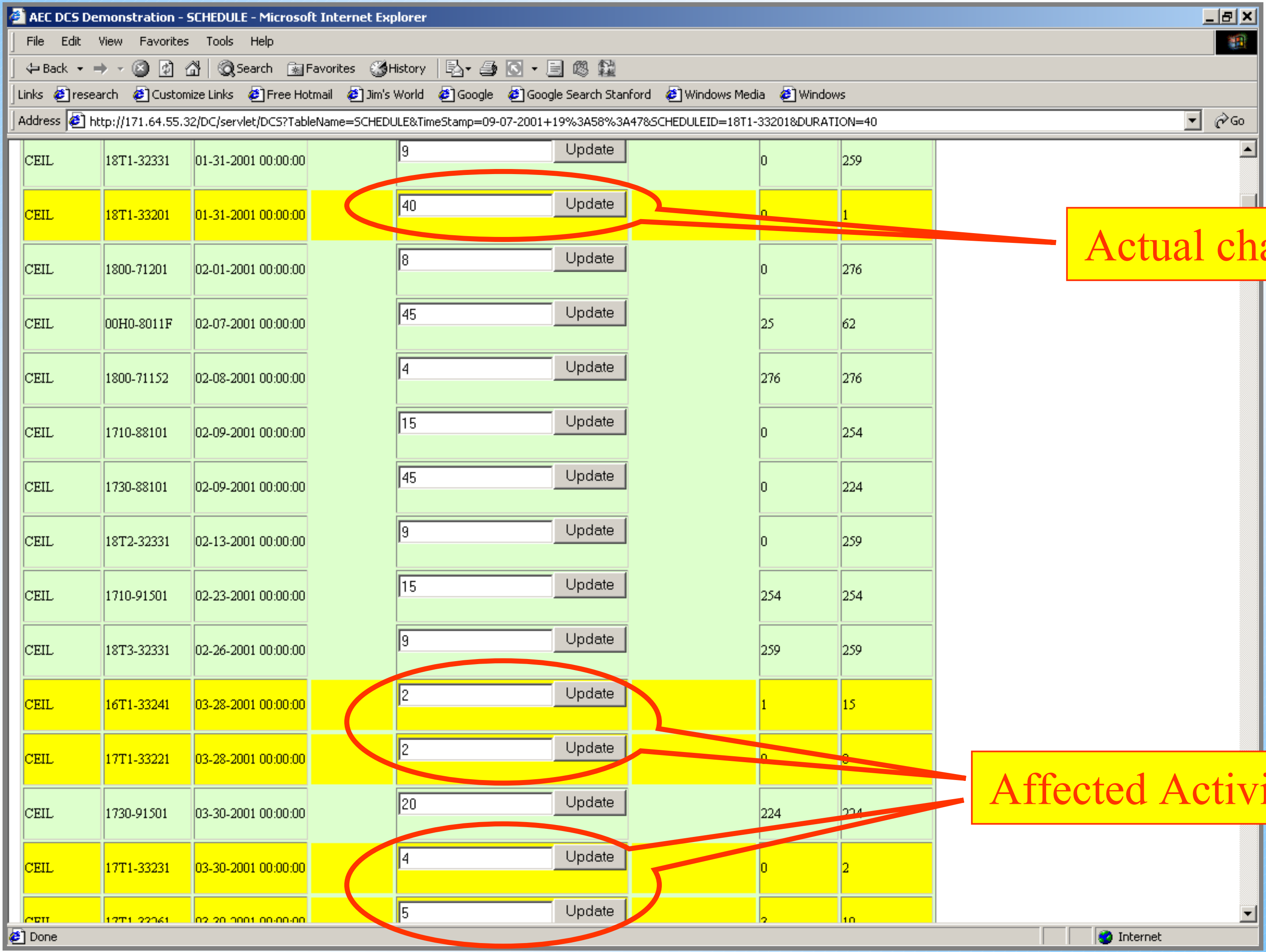

Microsoft Excel - exceldata1043198044210.csv
File Edit View Insert Format Tools Data Window Help
Arial
10
B

C158 = 40

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

Affected activity 18T1-33201

Review Changed Activities in Browser



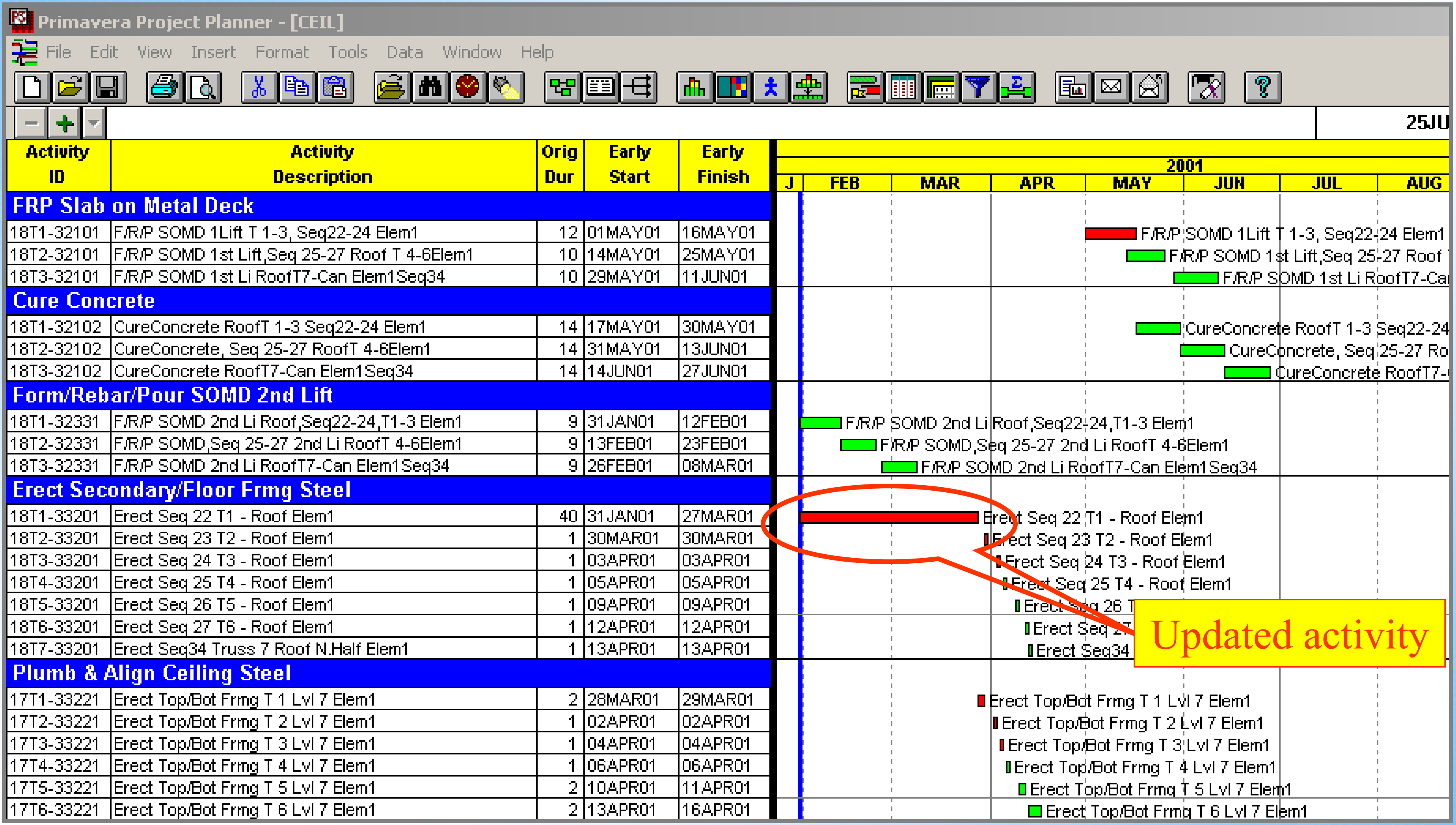
http://171.64.55.32/DC/servlet/DCS?TableName=SCHEDULE&TimeStamp=09-07-2001+19%3A58%3A47&SCHEDULEID=18T1-33201&DURATION=40

CEIL	18T1-32331	01-31-2001 00:00:00		9	Update		0	259
CEIL	18T1-33201	01-31-2001 00:00:00		40	Update		0	1
CEIL	1800-71201	02-01-2001 00:00:00		8	Update		0	276
CEIL	00H0-8011F	02-07-2001 00:00:00		45	Update		25	62
CEIL	1800-71152	02-08-2001 00:00:00		4	Update		276	276
CEIL	1710-88101	02-09-2001 00:00:00		15	Update		0	254
CEIL	1730-88101	02-09-2001 00:00:00		45	Update		0	224
CEIL	18T2-32331	02-13-2001 00:00:00		9	Update		0	259
CEIL	1710-91501	02-23-2001 00:00:00		15	Update		254	254
CEIL	18T3-32331	02-26-2001 00:00:00		9	Update		259	259
CEIL	16T1-33241	03-28-2001 00:00:00		2	Update		1	15
CEIL	17T1-33221	03-28-2001 00:00:00		2	Update		0	0
CEIL	1730-91501	03-30-2001 00:00:00		20	Update		224	224
CEIL	17T1-33231	03-30-2001 00:00:00		4	Update		0	2
CEIL	17T1-33261	03-30-2001 00:00:00		5	Update		3	10

Actual change

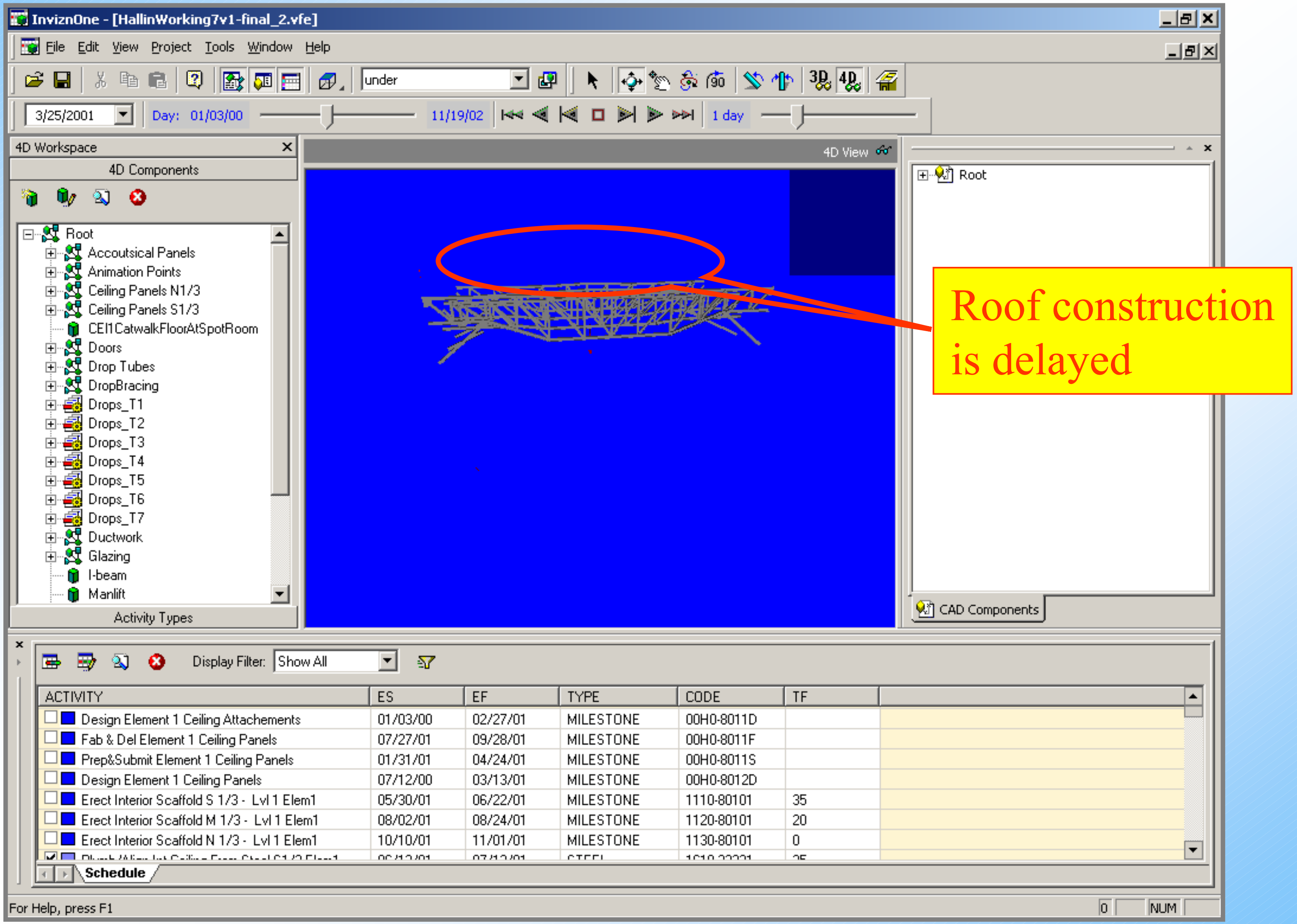
Affected Activities

Review Modified Schedule in Primavera


Primavera Project Planner - [CEIL]
File Edit View Insert Format Tools Data Window Help
25JU
2001
J FEB MAR APR MAY JUN JUL AUG
F/R/P SOMD 1Lift T 1-3, Seq22-24 Elem1
F/R/P SOMD 1st Lift,Seq 25-27 Roof
F/R/P SOMD 1st Li RoofT7-Ca
CureConcrete RoofT 1-3 Seq22-24
CureConcrete, Seq 25-27 Ro
CureConcrete RoofT7-
F/R/P SOMD 2nd Li Roof,Seq22-24,T1-3 Elem1
F/R/P SOMD,Seq 25-27 2nd Li RoofT 4-6Elem1
F/R/P SOMD 2nd Li RoofT7-Can Elem1Seq34
Erect Seq 22 T1 - Roof Elem1
Erect Seq 23 T2 - Roof Elem1
Erect Seq 24 T3 - Roof Elem1
Erect Seq 25 T4 - Roof Elem1
Erect Seq 26 T
Erect Seq 27
Erect Seq34
Erect Top/Bot Frmg T 1 Lvl 7 Elem1
Erect Top/Bot Frmg T 2 Lvl 7 Elem1
Erect Top/Bot Frmg T 3 Lvl 7 Elem1
Erect Top/Bot Frmg T 4 Lvl 7 Elem1
Erect Top/Bot Frmg T 5 Lvl 7 Elem1
Erect Top/Bot Frmg T 6 Lvl 7 Elem1
Updated activity

Activity ID	Activity Description	Orig Dur	Early Start	Early Finish
FRP Slab on Metal Deck				
18T1-32101	F/R/P SOMD 1Lift T 1-3, Seq22-24 Elem1	12	01MAY01	16MAY01
18T2-32101	F/R/P SOMD 1st Lift,Seq 25-27 Roof T 4-6Elem1	10	14MAY01	25MAY01
18T3-32101	F/R/P SOMD 1st Li RoofT7-Can Elem1Seq34	10	29MAY01	11JUN01
Cure Concrete				
18T1-32102	CureConcrete RoofT 1-3 Seq22-24 Elem1	14	17MAY01	30MAY01
18T2-32102	CureConcrete, Seq 25-27 RoofT 4-6Elem1	14	31MAY01	13JUN01
18T3-32102	CureConcrete RoofT7-Can Elem1Seq34	14	14JUN01	27JUN01
Form/Rebar/Pour SOMD 2nd Lift				
18T1-32331	F/R/P SOMD 2nd Li Roof,Seq22-24,T1-3 Elem1	9	31JAN01	12FEB01
18T2-32331	F/R/P SOMD,Seq 25-27 2nd Li RoofT 4-6Elem1	9	13FEB01	23FEB01
18T3-32331	F/R/P SOMD 2nd Li RoofT7-Can Elem1Seq34	9	26FEB01	08MAR01
Erect Secondary/Floor Frmg Steel				
18T1-33201	Erect Seq 22 T1 - Roof Elem1	40	31JAN01	27MAR01
18T2-33201	Erect Seq 23 T2 - Roof Elem1	1	30MAR01	30MAR01
18T3-33201	Erect Seq 24 T3 - Roof Elem1	1	03APR01	03APR01
18T4-33201	Erect Seq 25 T4 - Roof Elem1	1	05APR01	05APR01
18T5-33201	Erect Seq 26 T5 - Roof Elem1	1	09APR01	09APR01
18T6-33201	Erect Seq 27 T6 - Roof Elem1	1	12APR01	12APR01
18T7-33201	Erect Seq34 Truss 7 Roof N.Half Elem1	1	13APR01	13APR01
Plumb & Align Ceiling Steel				
17T1-33221	Erect Top/Bot Frmg T 1 Lvl 7 Elem1	2	28MAR01	29MAR01
17T2-33221	Erect Top/Bot Frmg T 2 Lvl 7 Elem1	1	02APR01	02APR01
17T3-33221	Erect Top/Bot Frmg T 3 Lvl 7 Elem1	1	04APR01	04APR01
17T4-33221	Erect Top/Bot Frmg T 4 Lvl 7 Elem1	1	06APR01	06APR01
17T5-33221	Erect Top/Bot Frmg T 5 Lvl 7 Elem1	2	10APR01	11APR01
17T6-33221	Erect Top/Bot Frmg T 6 Lvl 7 Elem1	2	13APR01	16APR01

Review Modified Design in 4D Viewer



under

3/25/2001 Day: 01/03/00 11/19/02 1 day

Roof construction is delayed

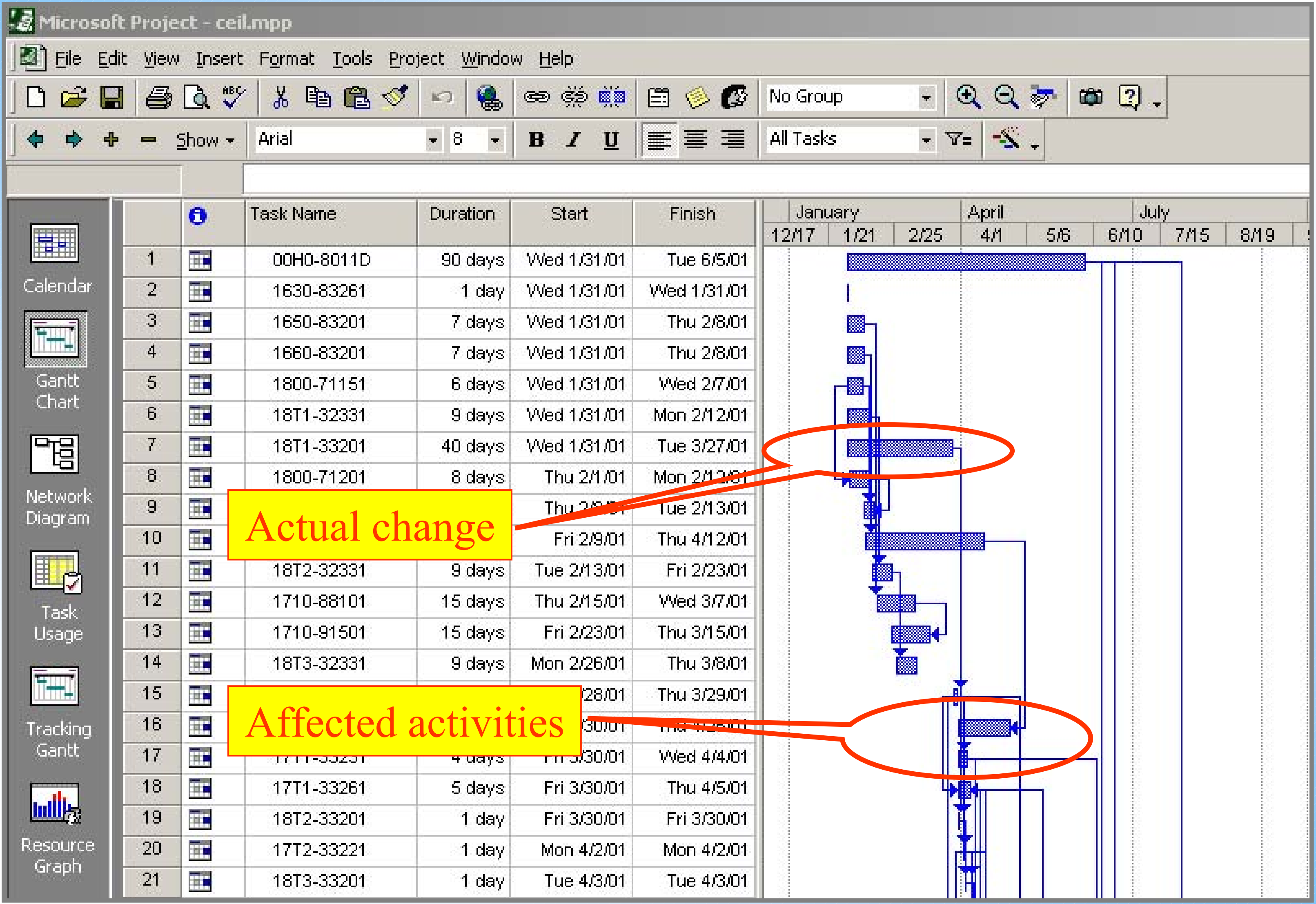
- Root
  - Accoutsical Panels
  - Animation Points
  - Ceiling Panels N1/3
  - Ceiling Panels S1/3
  - CEl1CatwalkFloorAtSpotRoom
  - Doors
  - Drop Tubes
  - DropBracing
  - Drops_T1
  - Drops_T2
  - Drops_T3
  - Drops_T4
  - Drops_T5
  - Drops_T6
  - Drops_T7
  - Ductwork
  - Glazing
  - I-beam
  - Manlift

Display Filter: Show All

ACTIVITY	ES	EF	TYPE	CODE	TF
□ Design Element 1 Ceiling Attachements	01/03/00	02/27/01	MILESTONE	00H0-8011D	
□ Fab & Del Element 1 Ceiling Panels	07/27/01	09/28/01	MILESTONE	00H0-8011F	
□ Prep&Submit Element 1 Ceiling Panels	01/31/01	04/24/01	MILESTONE	00H0-8011S	
□ Design Element 1 Ceiling Panels	07/12/00	03/13/01	MILESTONE	00H0-8012D	
□ Erect Interior Scaffold S 1/3 - Lvl 1 Elem1	05/30/01	06/22/01	MILESTONE	1110-80101	35
□ Erect Interior Scaffold M 1/3 - Lvl 1 Elem1	08/02/01	08/24/01	MILESTONE	1120-80101	20
□ Erect Interior Scaffold N 1/3 - Lvl 1 Elem1	10/10/01	11/01/01	MILESTONE	1130-80101	0
☑ Plumb/Align Int Ceiling Fram Steel S1/3 Elem1	06/12/01	07/12/01	STEEL	1610-22221	25

Schedule

Review Modified Schedule in Project



		Task Name	Duration	Start	Finish
1		00H0-8011D	90 days	Wed 1/31/01	Tue 6/5/01
2		1630-83261	1 day	Wed 1/31/01	Wed 1/31/01
3		1650-83201	7 days	Wed 1/31/01	Thu 2/8/01
4		1660-83201	7 days	Wed 1/31/01	Thu 2/8/01
5		1800-71151	6 days	Wed 1/31/01	Wed 2/7/01
6		18T1-32331	9 days	Wed 1/31/01	Mon 2/12/01
7		18T1-33201	40 days	Wed 1/31/01	Tue 3/27/01
8		1800-71201	8 days	Thu 2/1/01	Mon 2/12/01
9		[illegible]	[illegible]	[illegible]	Tue 2/13/01
10		[illegible]	[illegible]	Fri 2/9/01	Thu 4/12/01
11		18T2-32331	9 days	Tue 2/13/01	Fri 2/23/01
12		1710-88101	15 days	Thu 2/15/01	Wed 3/7/01
13		1710-91501	15 days	Fri 2/23/01	Thu 3/15/01
14		18T3-32331	9 days	Mon 2/26/01	Thu 3/8/01
15		[illegible]	[illegible]	[illegible]	Thu 3/29/01
16		[illegible]	[illegible]	[illegible]	[illegible]
17		[illegible]	4 days	Fri 3/30/01	Wed 4/4/01
18		17T1-33261	5 days	Fri 3/30/01	Thu 4/5/01
19		18T2-33201	1 day	Fri 3/30/01	Fri 3/30/01
20		17T2-33221	1 day	Mon 4/2/01	Mon 4/2/01
21		18T3-33201	1 day	Tue 4/3/01	Tue 4/3/01

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

D. Liu, J. Cheng, K. H. Law, G. Wiederhold, and R. D. Sriram. "An Engineering Information Service Infrastructure for Ubiquitous Computing", *Journal of Computing in Civil Engineering*, 2003.

D. Liu, J. Cheng, K. H. Law, and G. Wiederhold. "Ubiquitous Computing Environment for Project Management Services", *Proceedings of the Civil Engineering Conference and Exposition*, Washington DC, 2002.

D. Liu, K. H. Law, and G. Wiederhold. "Data-flow Distribution in FICAS Service Composition Infrastructure", *Proceedings of the 15th International Conference on Parallel and Distributed Computing Systems*, Louisville, KY, 2002.

D. Liu, K. H. Law, and G. Wiederhold. "Analysis of Integration Models for Service Composition", *Proceedings of the 3rd International Workshop on Software and Performance*, Rome, Italy, 2002.

D. Liu, K. H. Law, and G. Wiederhold. "CHAOS: An Active Security Mediation System", *Proceedings of the International Conference on Advanced Information Systems Engineering*, pp. 232-246, 2000.

D. Liu, J. Peng, K. H. Law, G. Wiederhold, and R. D. Sriram. “Composition of Autonomous Services with Distributed Data Flows and Computations", *Submitted to ACM Transactions on Internet Technology*, 2003.

J. Peng, D. Liu, and K. H. Law. "An Engineering Data Access System for a Finite Element Program", *Journal of Advances in Engineering Software*, vol. 34(3), pp. 163-181, 2003.

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

End of Presentation

Thank You