RWTH AACHEN UNIVERSITY

BUSINESS ANALYTICS AND OPTIMIZATION

INTERNATIONAL CONFERENCE ON
OPERATIONS RESEARCH 2014 IN AACHEN

SEPTEMBER 2-5, 2014

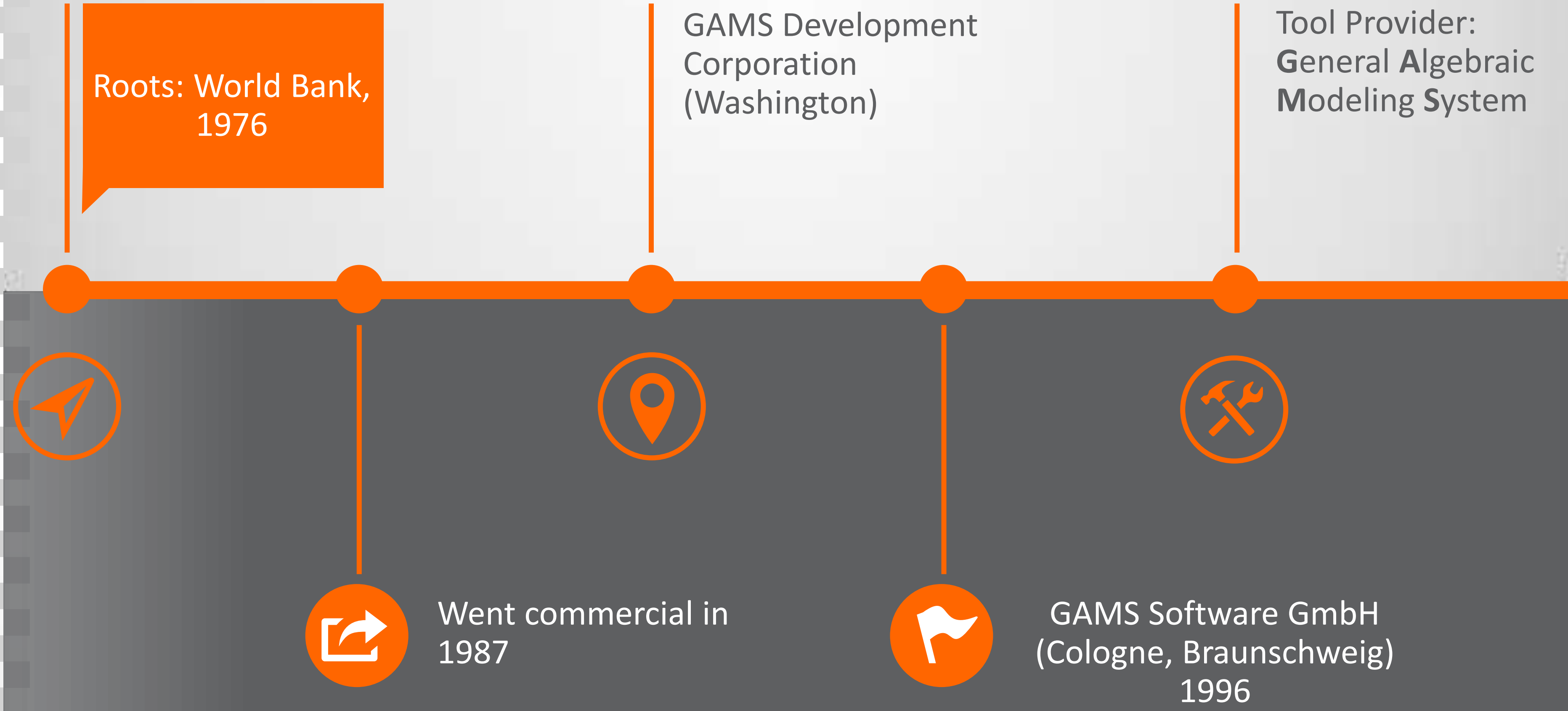
GOR

GAMS

Design Principles that Make the Difference

Franz Nelissen: FNelissen@gams.com

Company Background



Roots: World Bank, 1976

Went commercial in 1987

GAMS Development Corporation (Washington)

GAMS Software GmbH (Cologne, Braunschweig) 1996

Tool Provider: **G**eneral **A**lgebraic **M**odeling **S**ystem

Agenda

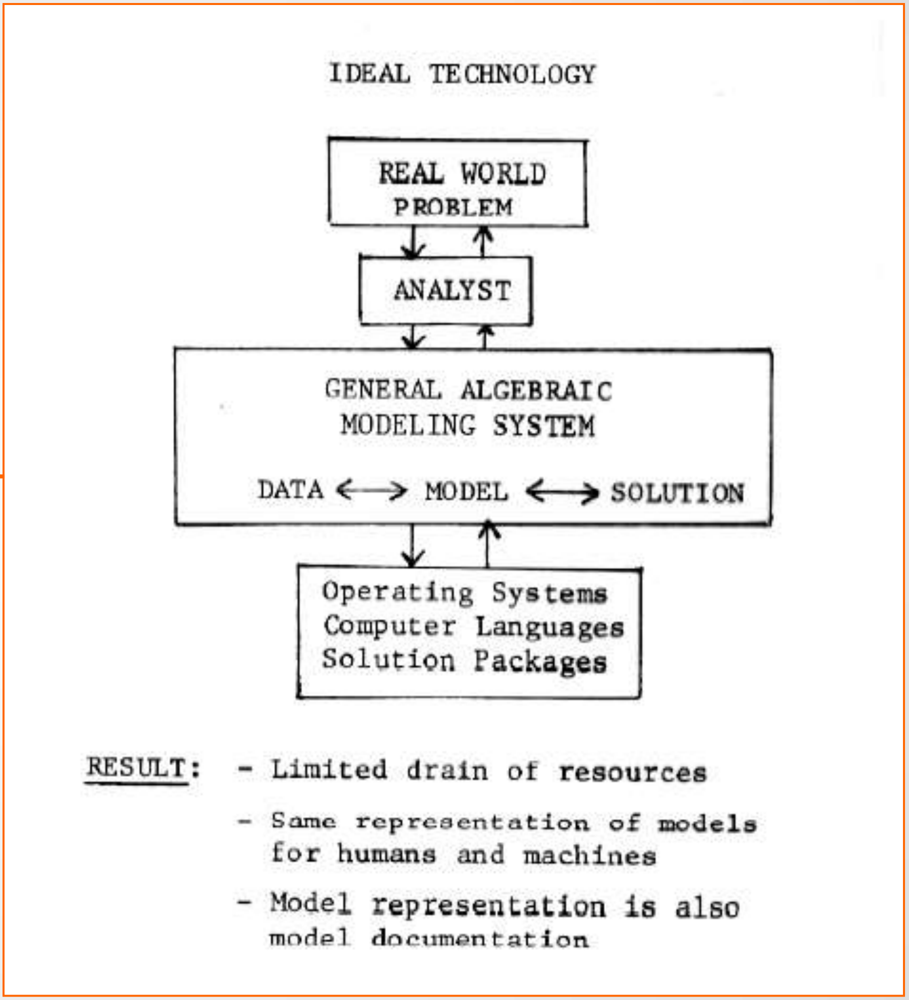
Algebraic Modeling Languages – A Success Story

GAMS – Highlights and Design Principles

Model Deployment

1976 - A World Bank Slide

The Vision



IDEAL TECHNOLOGY

REAL WORLD PROBLEM

ANALYST

GENERAL ALGEBRAIC MODELING SYSTEM

DATA ⟷ MODEL ⟷ SOLUTION

Operating Systems
Computer Languages
Solution Packages

RESULT:
- Limited drain of resources
- Same representation of models for humans and machines
- Model representation is also model documentation

Algebraic Modeling Languages (AML)

1

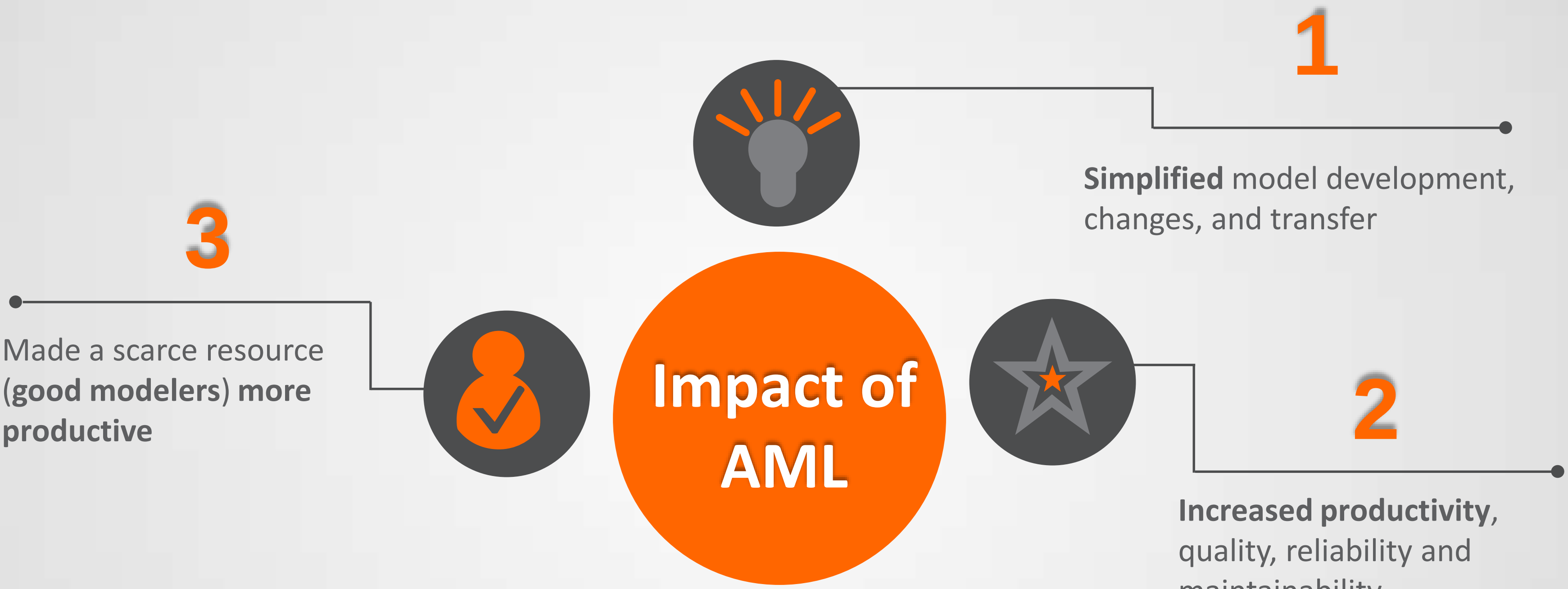
- High-level **computer programming languages**
  - Formulation of **mathematical optimization problems**
  - **Notation similar to algebraic notation**

2

- **Do not solve problems directly**, but offer links to state-of-the-art algorithms (“solver-links”)

Source: http://en.wikipedia.org/wiki/Algebraic_modeling_language

Impact of Algebraic Modeling Languages



Impact of AML

1

Simplified model development, changes, and transfer

2

Increased productivity, quality, reliability and maintainability

3

Made a scarce resource (**good modelers) more productive**

- **Important vehicle to make mathematical optimization available to a broader audience**

2012 INFORMS Impact Prize

36 Years

later

Originators of Algebraic Modeling Languages

AIMMS 3

AMPL

MAXIMAL SOFTWARE

GAMS

LINDO SYSTEMS

Agenda

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Model Deployment

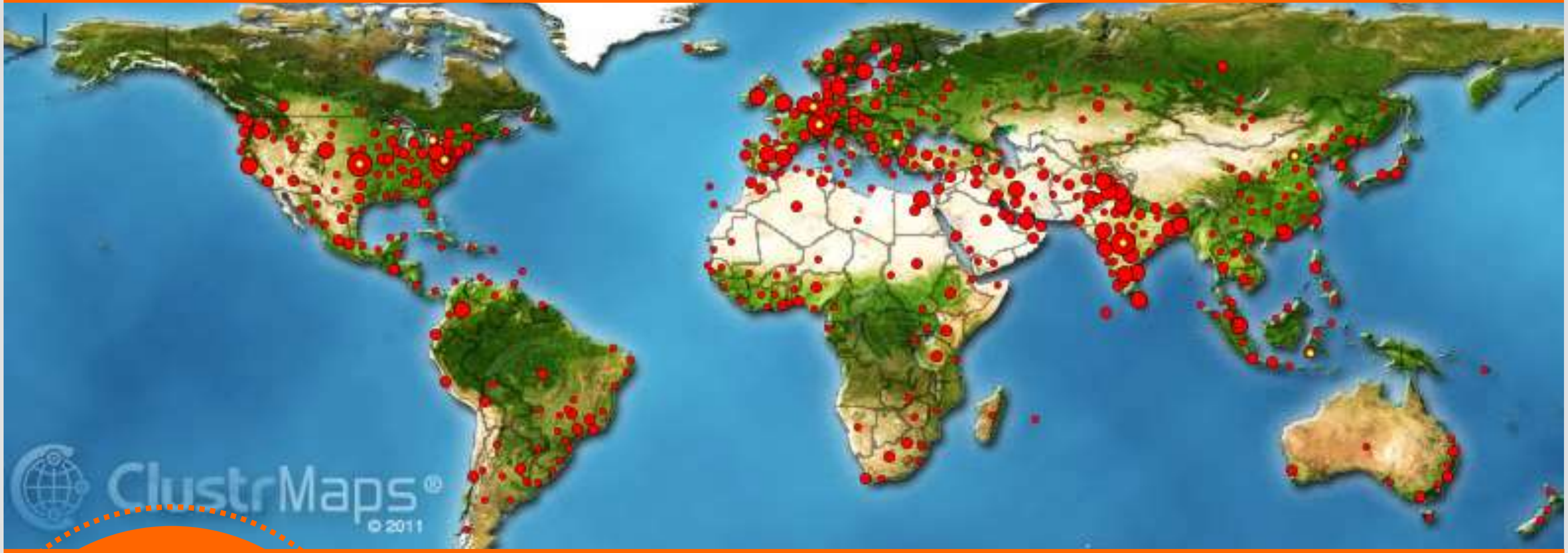
What does he have to think about?

1. Problem
2. Mathematics
3. Programming
4. Performance
5. Scalability
6. Connectivity
7. Deployment
8. Maintenance (Life Cycle)
9. ...

➢ **Why use an AML like GAMS?**

Broad User Community and Network

GAMS used in more than 120 countries

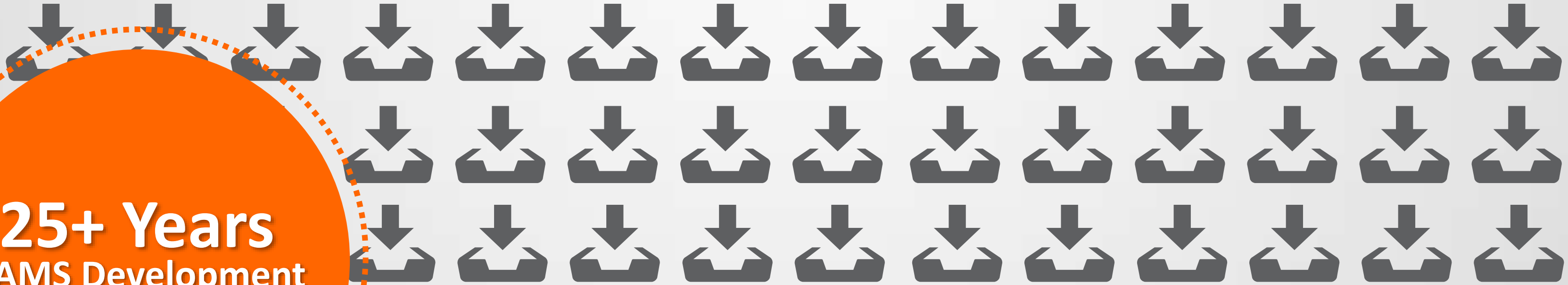


25+ Years
GAMS Development

Broad User Community and Network

More than 10,000 licenses

50% academic users, 50% commercial users



25+ Years
GAMS Development

6,000+ monthly downloads of the free system

Broad Range of Application Areas

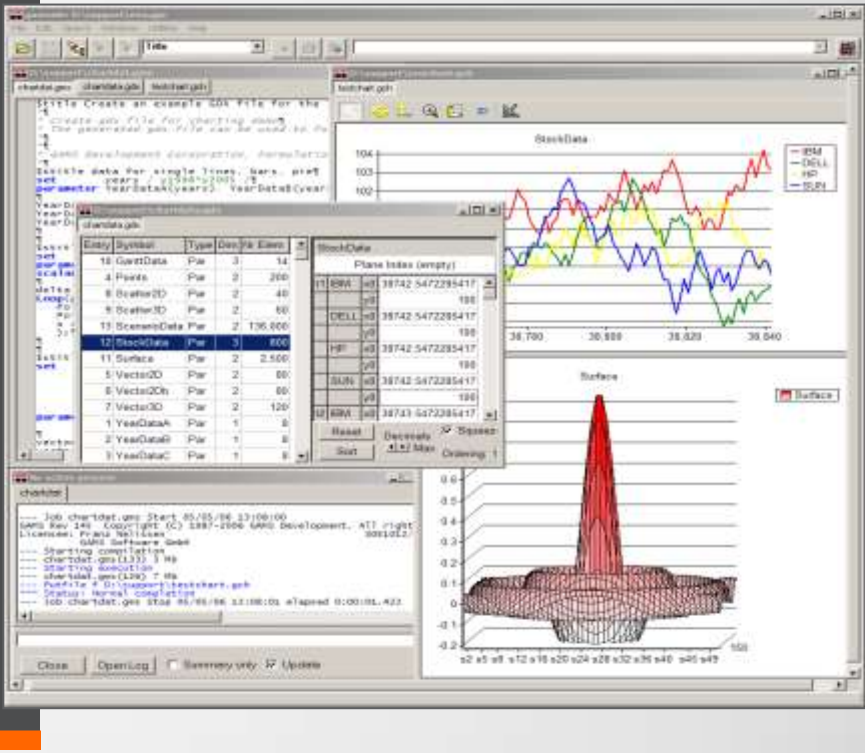
- Agricultural Economics
- Applied General Equilibrium
- Chemical Engineering
- Economic Development
- Econometrics
- Energy
- Environmental Economics
- Engineering
- Finance
- Forestry
- International Trade
- Logistics
- Macro Economics
- Military
- Management Science/OR
- Mathematics
- Micro Economics
- Physics

25+ Years
GAMS Development

Strong Development Environment

GAMS IDE

- Project management
- Editor / Syntax coloring / Spell checks
- Listing file / Tree view / Syntax-error navigation
- Model Debugging / Profiling
- Solver selection / Option selection
- Data viewer
  - Export
  - Charting
- GAMS Process Control
- Model Libraries -1250 Models included



Entry	Symbol	Type	Dim	Nr Elem
10	GanttData	Par	3	14
4	Points	Par	2	200
8	Scatter2D	Par	2	40
9	Scatter3D	Par	2	60
13	ScenarioData	Par	2	136,000
12	StockData	Par	3	800
11	Surface	Par	2	2,500
5	Vector2D	Par	2	80
6	Vector2Dh	Par	2	80
7	Vector3D	Par	2	120
1	YearDataA	Par	1	8
2	YearDataB	Par	1	8
3	YearDataC	Par	1	8

```
--- Job chartdat.gms Start 05/05/06 13:08:00
GAMS Rev 146  Copyright (C) 1987-2006 GAMS Development. All rights
Licensee: Franz Nelissen                                   G051012
          GAMS Software GmbH
--- Starting compilation
--- chartdat.gms(113) 3 Mb
--- Starting execution
--- chartdat.gms(129) 7 Mb
--- Putfile ? D:\support\testchart.gch
--- Status: Normal completion
--- Job chartdat.gms Stop 05/05/06 13:08:01 elapsed 0:00:01.422
```

→ **Everything for rapid model development**

Design Principles

1

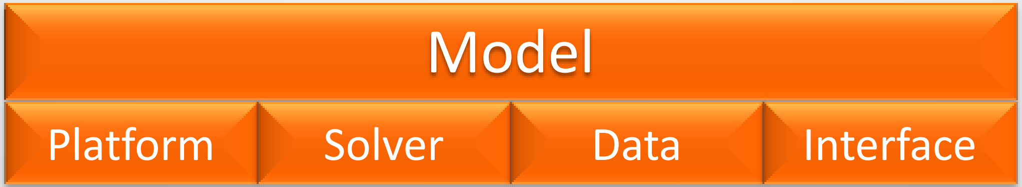
- Simple modeling language with a balanced mix of declarative and procedural elements

2

- Open architecture and interfaces to other systems

3

- Independent layers

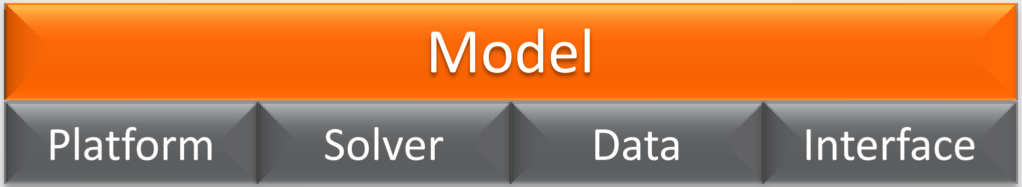


Simple Declarative Language

1
- Language similar to mathematical notation

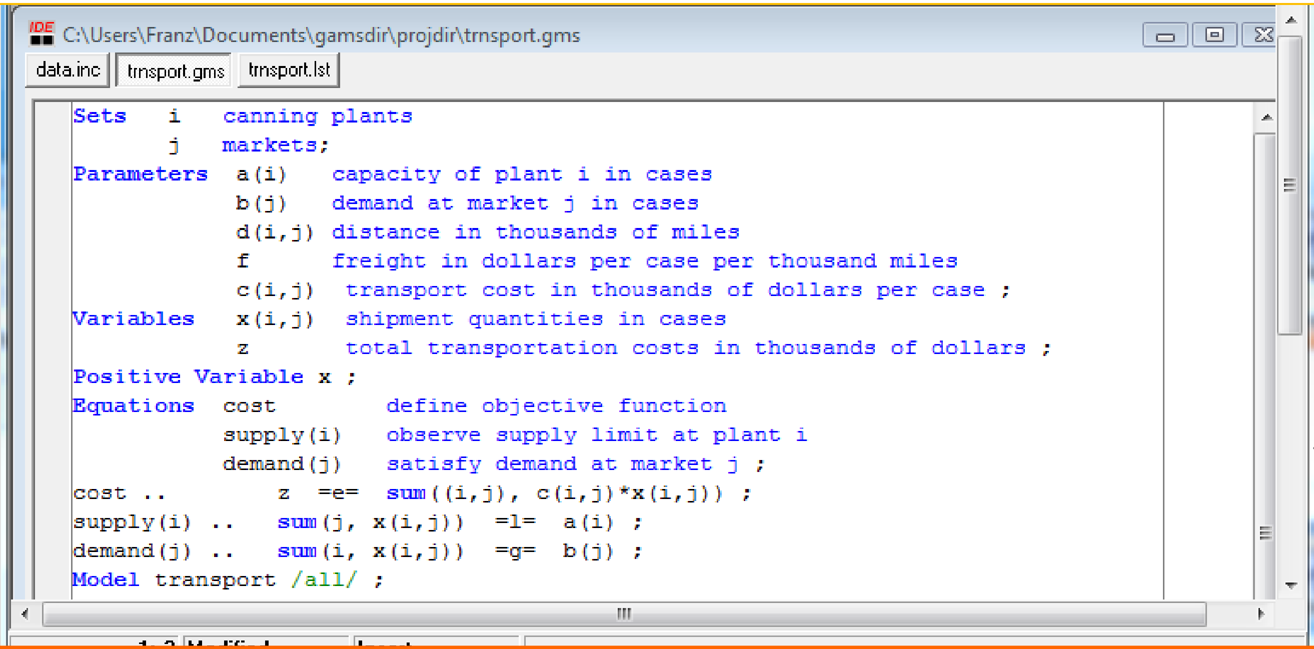
2
- Few basic language elements: sets, parameters, variables, equations, models → Easy to learn

3
- Lot's of code optimization under the hood



Example

$$
\begin{array}{llll}
\text{Objective} & \sum_i \sum_j c_{i,j} \times x_{i,j} & \longrightarrow \min & \\
\text{Observe supply limit at plant } i\text{:} & \sum_j x_{i,j} & \leq a_i & \forall i \\
\text{Satisfy demand at market } j\text{:} & \sum_i x_{i,j} & \geq b_j & \forall j \\
 & x_{i,j} & \geq 0 & \forall i,j
\end{array}
$$



```
Sets   i   canning plants
       j   markets;
Parameters  a(i)   capacity of plant i in cases
            b(j)   demand at market j in cases
            d(i,j) distance in thousands of miles
            f      freight in dollars per case per thousand miles
            c(i,j)  transport cost in thousands of dollars per case ;
Variables   x(i,j)  shipment quantities in cases
            z       total transportation costs in thousands of dollars ;
Positive Variable x ;
Equations  cost        define objective function
           supply(i)   observe supply limit at plant i
           demand(j)   satisfy demand at market j ;
cost ..        z  =e=  sum((i,j), c(i,j)*x(i,j)) ;
supply(i) ..   sum(j, x(i,j))  =l=  a(i) ;
demand(j) ..   sum(i, x(i,j))  =g=  b(j) ;
Model transport /all/ ;
```

- ➢ **Model is executable description of the problem**

Mix of Declarative and Procedural Elements

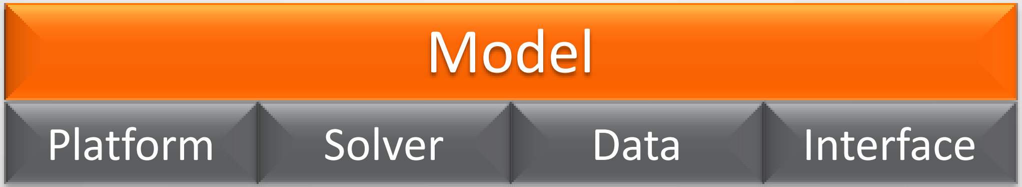
Procedural elements like loops, for, if, macros and functions

Allow to build complex problem algorithms within GAMS

Interaction with other systems:

- Job control
- Data exchange

➢ Combine models inside the language

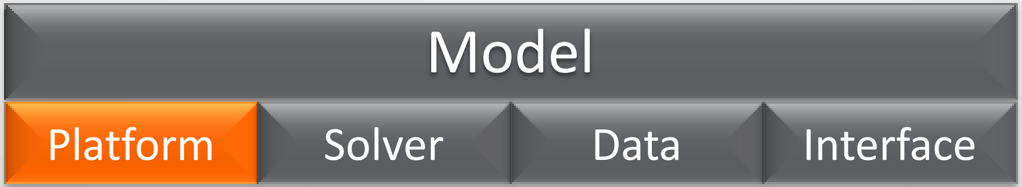


Independence of Model and Operating System

Platforms supported by GAMS:

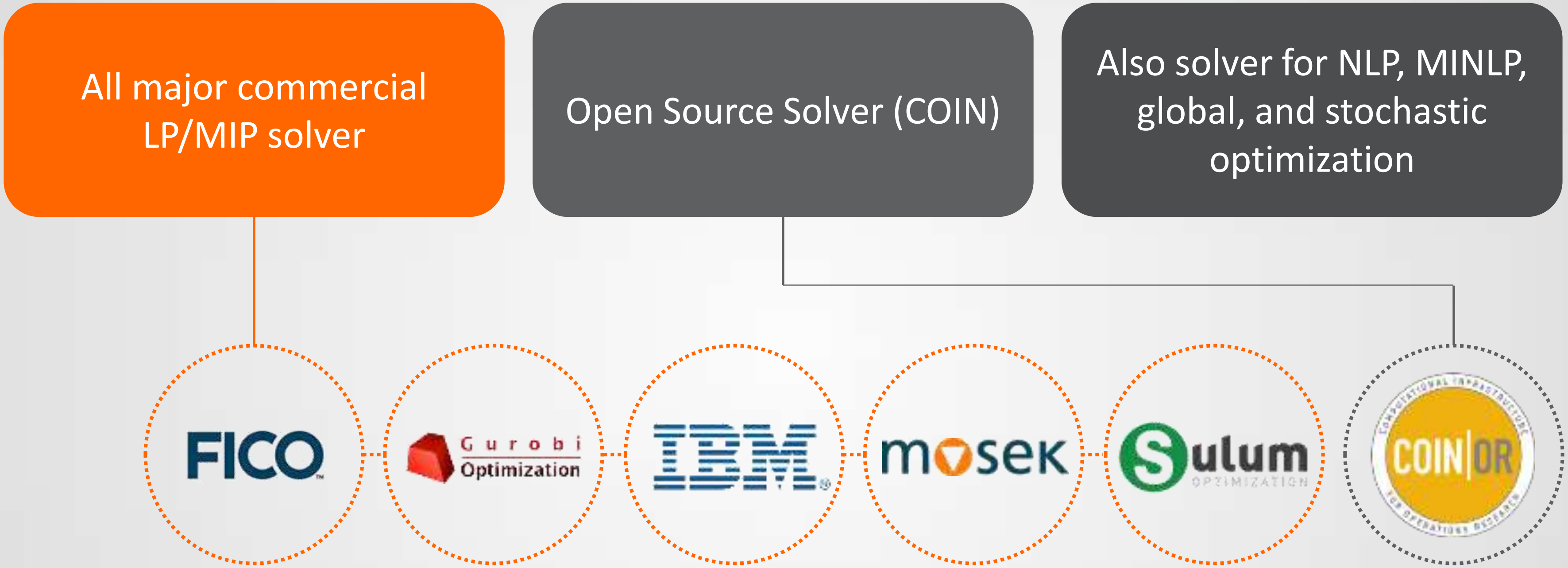
Microsoft Windows
Linux
X
Welcome to Mac OS X
solaris
AIX

- Models can be moved between platforms with ease!



Independence of Model and Solver

One environment for a wide range of model types and solvers



All major commercial LP/MIP solver

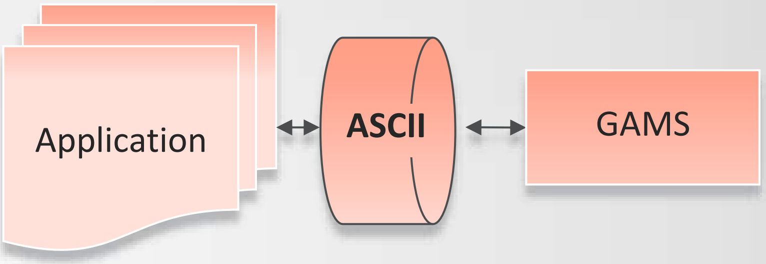
Open Source Solver (COIN)

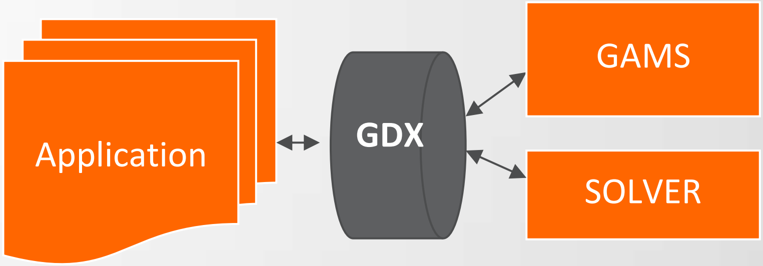
Also solver for NLP, MINLP, global, and stochastic optimization

- ➢ **Switching between solvers with one line of code!**

Independence of Model and Data

- **Declarative Modeling**: *x(j), j∈{1,…}*
  - ASCII: Initial model development
  - GDX: Binary Data layer ("contract") between GAMS and applications
    - Platform independent
    - Direct GDX interfaces and general API





Independence of Model and User Interface

1

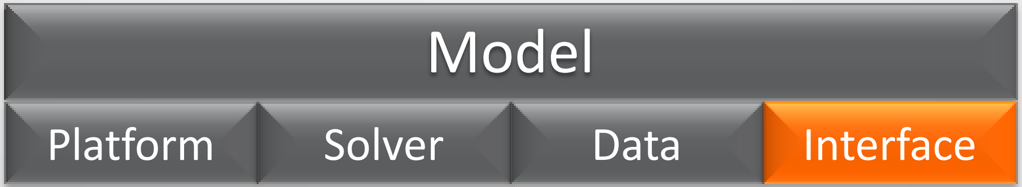
- **Open architecture and interfaces to other systems → No preference for a particular user interface**

2

- Application Programming Interfaces
  - *Low Level*
  - **Object Oriented**: .Net, Java, Python, …

3

- **Smart Links to popular environments**
  - **Excel, MATLAB, R, …**


Model

Platform

Solver

Data

Interface

Agenda

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GAMS – Highlights and Design Principles

Model Deployment

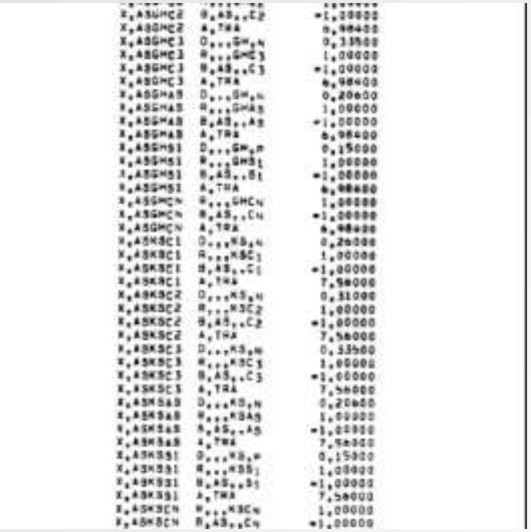
Is Optimization special?

Observation:

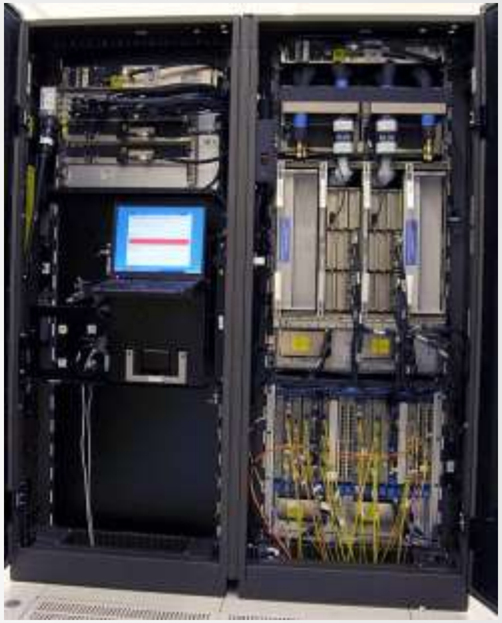
Optimization models
- are expensive to develop
- may have long a lifespan

Modeling Systems & Applications have to be adjusted
- New computer paradigms
- New solver technology and solution methods
- New graphical user interfaces and deployment environments

Change in Focus: Past



```
X,ASGMC2  B,AS..C2        -1,00000
X,ASGMC2  A,TRA            6,98400
X,ASGMC3  D...GM,N         0,33500
X,ASGMC3  R...GMC3         1,00000
X,ASGMC3  B,AS..C3        -1,00000
X,ASGMC3  A,TRA            6,98400
X,ASGMAS  D...GM,N         0,20600
X,ASGMAS  R...GMAS         1,00000
X,ASGMAS  B,AS..AS        -1,00000
X,ASGMAS  A,TRA            6,98400
X,ASGMS1  D...GM,M         0,15000
X,ASGMS1  R...GMS1         1,00000
X,ASGMS1  B,AS..S1        -1,00000
X,ASGMS1  A,TRA            6,98400
X,ASGMCN  R...GMCN         1,00000
X,ASGMCN  B,AS..CN        -1,00000
X,ASGMCN  A,TRA            6,98400
X,ASKSC1  D...KS,N         0,26000
X,ASKSC1  R...KSC1         1,00000
X,ASKSC1  B,AS..C1        -1,00000
X,ASKSC1  A,TRA            7,50000
X,ASKSC2  D...KS,N         0,31000
X,ASKSC2  R...KSC2         1,00000
X,ASKSC2  B,AS..C2        -1,00000
X,ASKSC2  A,TRA            7,56000
X,ASKSC3  D...KS,N         0,33500
X,ASKSC3  R...KSC3         1,00000
X,ASKSC3  B,AS..C3        -1,00000
X,ASKSC3  A,TRA            7,56000
X,ASKSAS  D...KS,N         0,20600
X,ASKSAS  R...KSAS         1,00000
X,ASKSAS  B,AS..AS        -1,00000
X,ASKSAS  A,TRA            7,56000
X,ASKSS1  D...KS,M         0,15000
X,ASKSS1  R...KSS1         1,00000
X,ASKSS1  B,AS..S1        -1,00000
X,ASKSS1  A,TRA            7,56000
X,ASKSCN  R...KSCN         1,00000
X,ASKSCN  B,AS..CN        -1,00000
```



Computation

Users:

→ Left out

Model

Users:

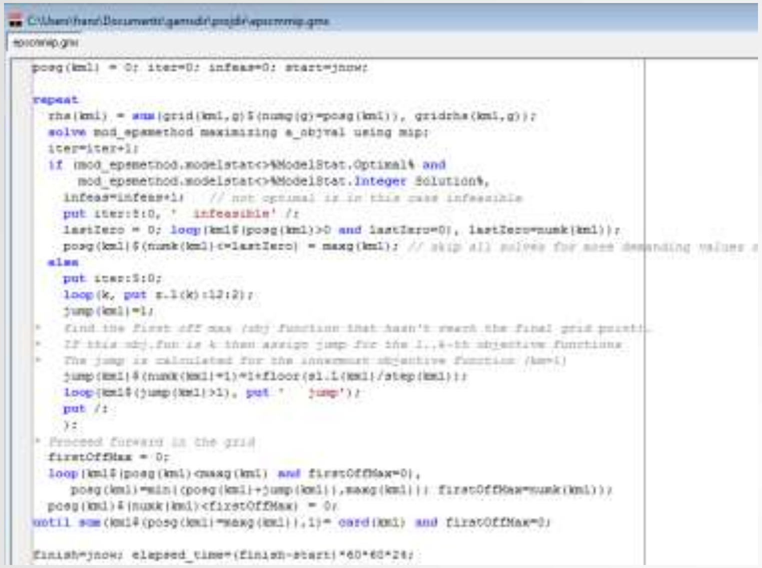
→ Involved

Application

Users:

→Not aware of model

Change in Focus: Now



```
posg(km1) = 0; iter=0; infeas=0; start=jnow;

repeat
  rhs(km1) = sum(grid(km1,g)$(numg(g)=posg(km1)), gridrhs(km1,g));
  solve mod_epsmethod maximizing a_objval using mip;
  iter=iter+1;
  if (mod_epsmethod.modelstat<>%ModelStat.Optimal% and
      mod_epsmethod.modelstat<>%ModelStat.Integer Solution%,
    infeas=infeas+1;   // not optimal is in this case infeasible
    put iter:5:0, '  infeasible' /;
    lastZero = 0; loop(km1$(posg(km1)>0 and lastZero=0), lastZero=numk(km1));
    posg(km1)$(numk(km1)<=lastZero) = maxg(km1); // skip all solves for more demanding values o
  else
    put iter:5:0;
    loop(k, put z.l(k):12:2);
    jump(km1)=1;
*   find the first off max (obj function that hasn't reach the final grid point).
*   If this obj.fun is k then assign jump for the 1..k-th objective functions
*   The jump is calculated for the innermost objective function (km=1)
    jump(km1)$(numk(km1)=1)=1+floor(sl.L(km1)/step(km1));
    loop(km1$(jump(km1)>1), put '   jump');
    put /;
    );
* Proceed forward in the grid
  firstOffMax = 0;
  loop(km1$(posg(km1)<maxg(km1) and firstOffMax=0),
     posg(km1)=min((posg(km1)+jump(km1)),maxg(km1)); firstOffMax=numk(km1));
  posg(km1)$(numk(km1)<firstOffMax) = 0;
until sum(km1$(posg(km1)=maxg(km1)),1)= card(km1) and firstOffMax=0;

finish=jnow; elapsed_time=(finish-start)*60*60*24;
```

Computation

Users:

→ Left out

Model

Users:

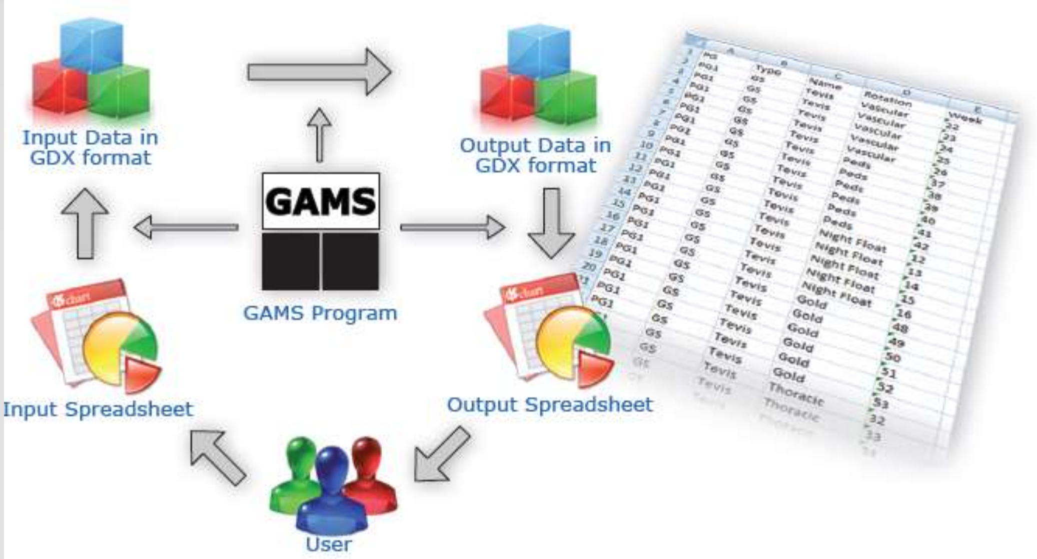
→ Involved

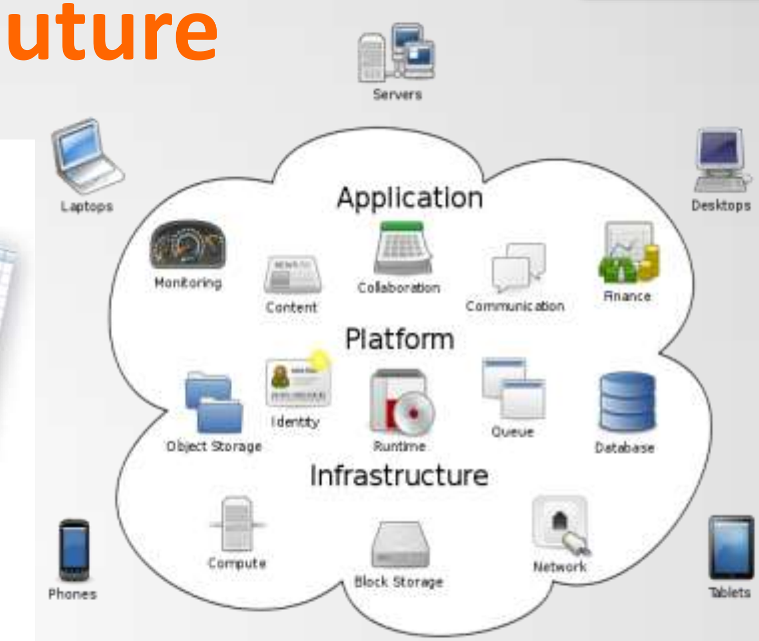
Application

Users:

→Not aware of model

Change in Focus: Now / Future





Cloud Computing

Computation

Users:

→ Left out

Model

Users:

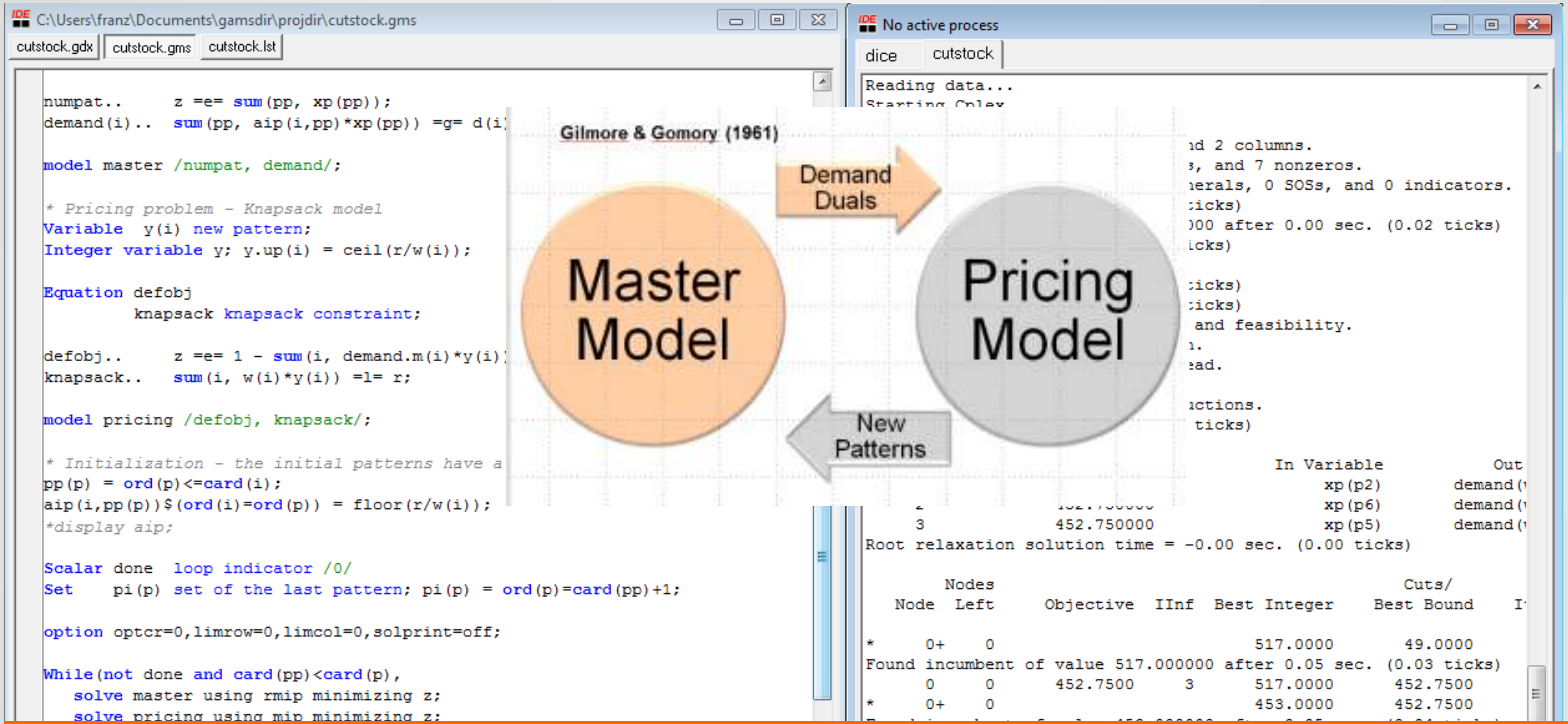
→ Involved

Application

Users:

→Not aware of model

Change in Focus: Modeler…

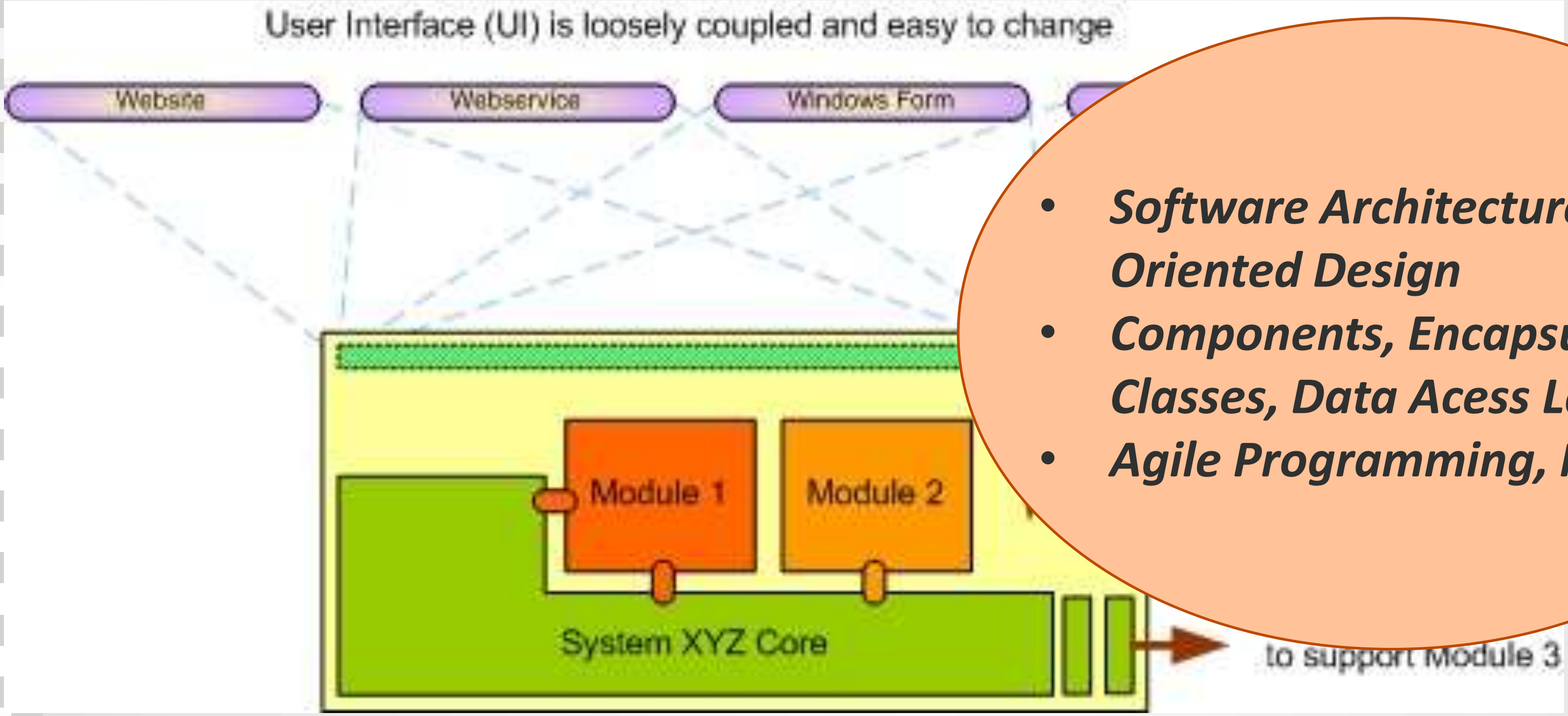


```
numpat..      z =e= sum(pp, xp(pp));
demand(i)..   sum(pp, aip(i,pp)*xp(pp)) =g= d(i

model master /numpat, demand/;

* Pricing problem - Knapsack model
Variable  y(i) new pattern;
Integer variable y; y.up(i) = ceil(r/w(i));

Equation defobj
         knapsack knapsack constraint;

defobj..      z =e= 1 - sum(i, demand.m(i)*y(i)
knapsack..    sum(i, w(i)*y(i)) =l= r;

model pricing /defobj, knapsack/;

* Initialization - the initial patterns have a
pp(p)  = ord(p)<=card(i);
aip(i,pp(p))$(ord(i)=ord(p))  = floor(r/w(i));
*display aip;

Scalar done  loop indicator /0/
Set    pi(p) set of the last pattern; pi(p) = ord(p)=card(pp)+1;

option optcr=0,limrow=0,limcol=0,solprint=off;

While(not done and card(pp)<card(p),
   solve master using rmip minimizing z;
   solve pricing using mip minimizing z;
```

```
Reading data...
Starting Cplex
                                     nd 2 columns.
                                     s, and 7 nonzeros.
                                     nerals, 0 SOSs, and 0 indicators.
                                     ticks)
                                     000 after 0.00 sec. (0.02 ticks)
                                     icks)

                                     ticks)
                                     ticks)
                                      and feasibility.
                                     n.
                                     ead.

                                     actions.
                                      ticks)

                                              In Variable          Out
                                                   xp(p2)        demand(
                                                   xp(p6)        demand(
      3              452.750000                    xp(p5)        demand(
Root relaxation solution time = -0.00 sec. (0.00 ticks)

        Nodes                                                   Cuts/
   Node  Left     Objective  IInf  Best Integer     Best Bound    I

*     0+    0                          517.0000        49.0000
Found incumbent of value 517.000000 after 0.05 sec. (0.03 ticks)
      0     0      452.7500     3      517.0000       452.7500
*     0+    0                          453.0000       452.7500
```

- Small Community: 2010 ~ 64,000 OR Analytic Professionals in the US

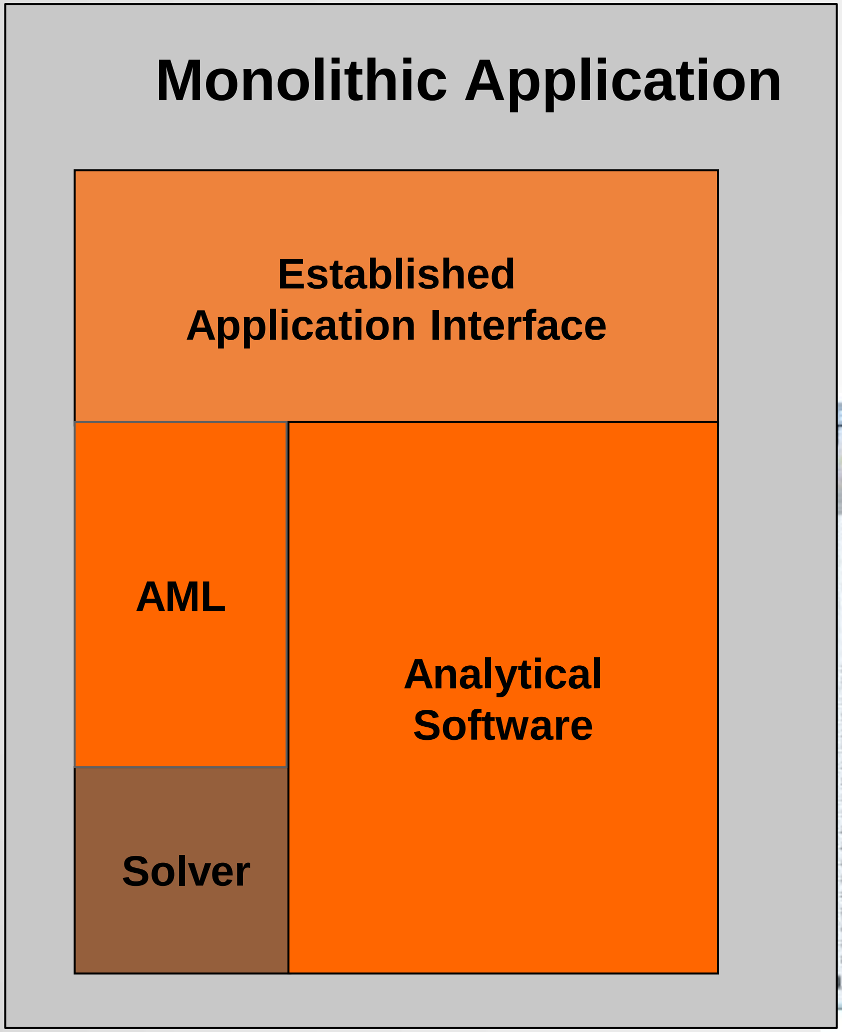
Change in Focus: Application Developer



- *Software Architecture, Object Oriented Design*
- *Components, Encapsulation, Classes, Data Acess Layer,..*
- *Agile Programming, Mesh, …*

- **Huge Community: 2006 ~ 3.3 Mill. IT Professionals in the US (2006)**
- **Rapidly changing IT environments**

Example – All in One – Top Down



Monolithic Application

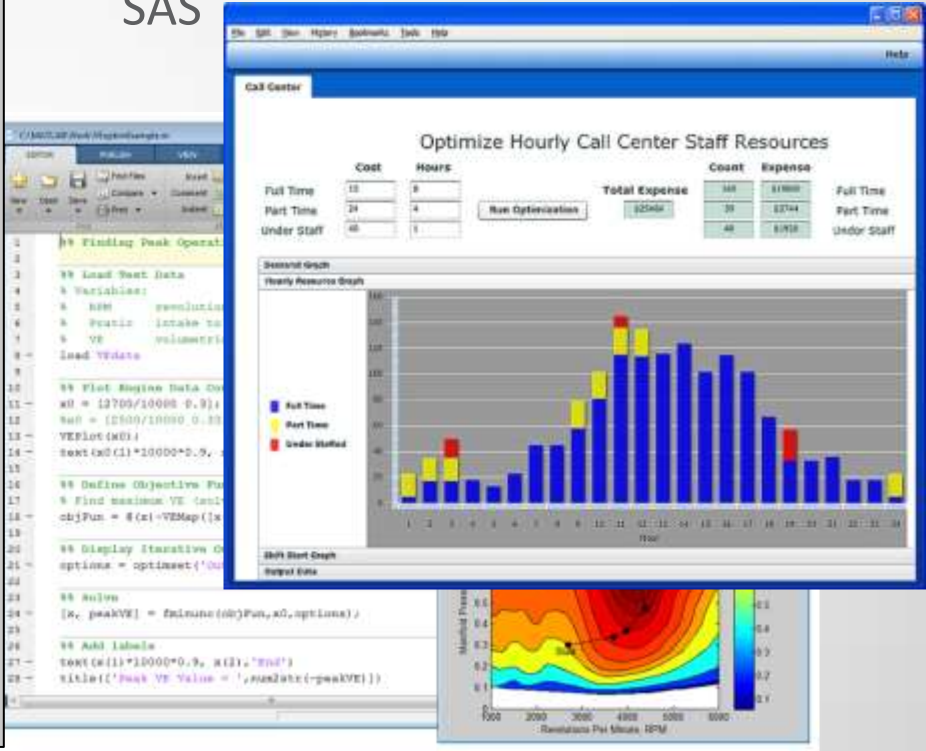
Established Application Interface

AML

Analytical Software

Solver

- Add “AML” to existing analytical software system
- “large” user base, e.g. MATLAB, or SAS



```
%% Finding Peak Operat
%% Load Test Data
% Variables:
%   RPM      revolution
%   Pratio   intake to
%   VE       volumetric
load VEdata

%% Plot Engine Data Co
x0 = [2700/10000 0.3];
%x0 = [2500/10000 0.33
VEPlot(x0);
text(x0(1)*10000*0.9,

%% Define Objective Fu
% Find maximum VE (onl
objFun = @(x)-VEMap([x

%% Display Iterative O
options = optimset('Di

%% Solve
[x, peakVE] = fminunc(objFun,x0,options);

%% Add labels
text(x(1)*10000*0.9, x(2),'End')
title(['Peak VE Value = ',num2str(-peakVE)])
```

Call Center

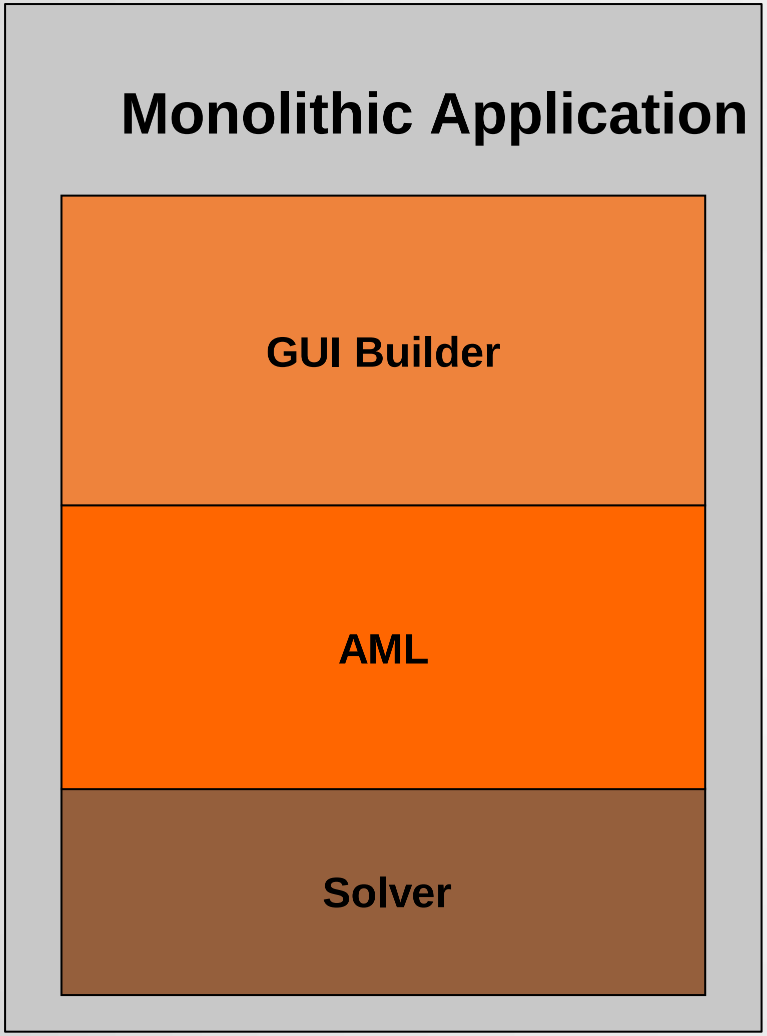
Optimize Hourly Call Center Staff Resources

	Cost	Hours
Full Time	15	8
Part Time	24	4
Under Staff	40	1

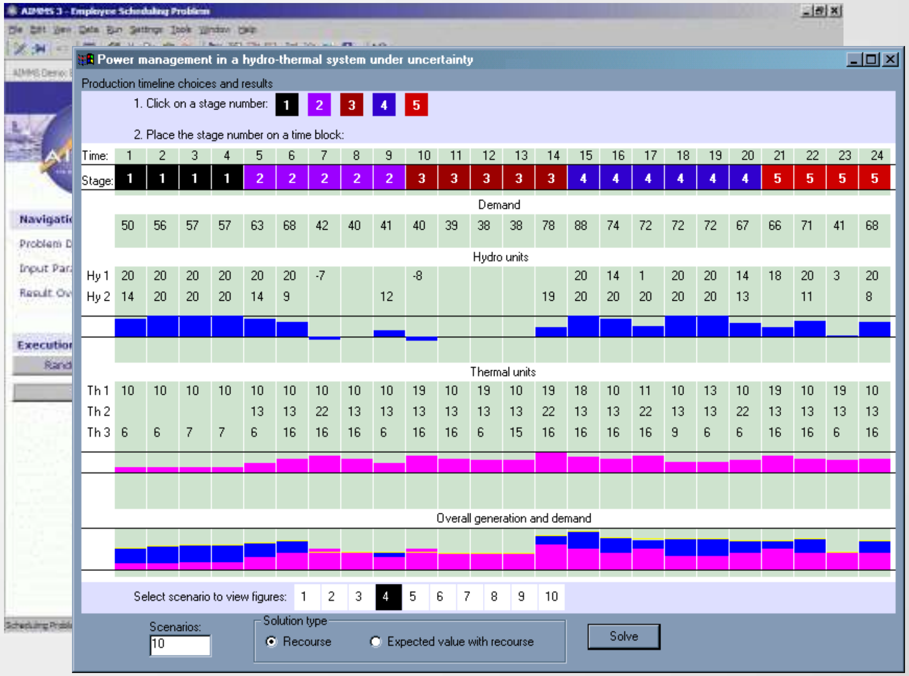
Total Expense

Count	Expense	
168	[illegible]	Full Time
39	[illegible]	Part Time
48	[illegible]	Under Staff

Example – All in One – Bottom Up



- Integrate GUI-builder into AML
- “small” user base, e.g. AIMMS (Pro) or FICO Xpress-Insight


AIMMS 3 - Employee Scheduling Problem
File Edit View Data Run Settings Tools Window Help
Navigation
Execution

Power management in a hydro-thermal system under uncertainty

Production timeline choices and results

1. Click on a stage number: 1 2 3 4 5

2. Place the stage number on a time block:

Time:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Stage:	1	1	1	1	2	2	2	2	2	3	3	3	3	3	4	4	4	4	4	4	5	5	5	5
Demand																								
	50	56	57	57	63	68	42	40	41	40	39	38	38	78	88	74	72	72	72	67	66	71	41	68
Hydro units																								
Hy 1	20	20	20	20	20	20	-7			-8					20	14	1	20	20	14	18	20	3	20
Hy 2	14	20	20	20	14	9			12					19	20	20	20	20	20	13		11		8
Thermal units																								
Th 1	10	10	10	10	10	10	10	10	10	19	10	19	10	19	18	10	11	10	13	10	19	10	19	10
Th 2					13	13	22	13	13	13	13	13	13	22	13	13	22	13	13	22	13	13	13	13
Th 3	6	6	7	7	6	16	16	16	6	16	16	6	15	16	16	16	16	9	6	6	16	16	6	16

Overall generation and demand

Select scenario to view figures: 1 2 3 4 5 6 7 8 9 10

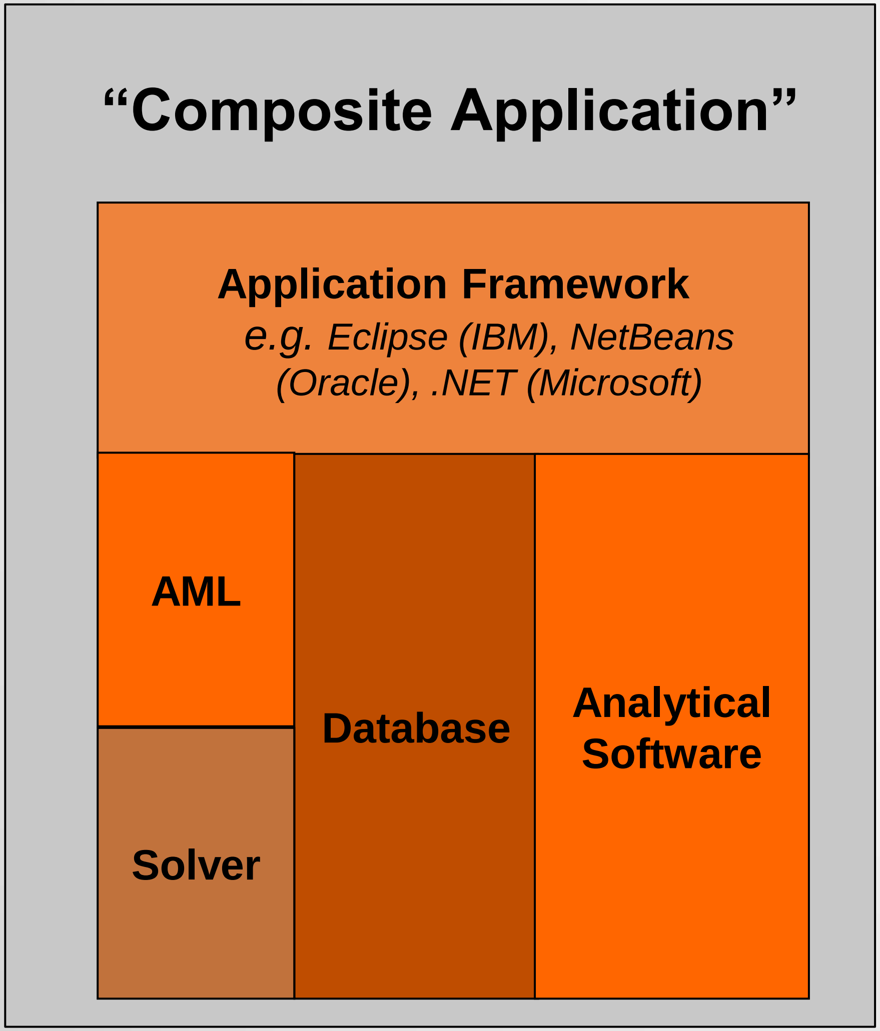
Scenarios: 10

Solution type

● Recourse ○ Expected value with recourse

Solve

Example – Composite Application



"Composite Application"

Application Framework
e.g. Eclipse (IBM), NetBeans (Oracle), .NET (Microsoft)

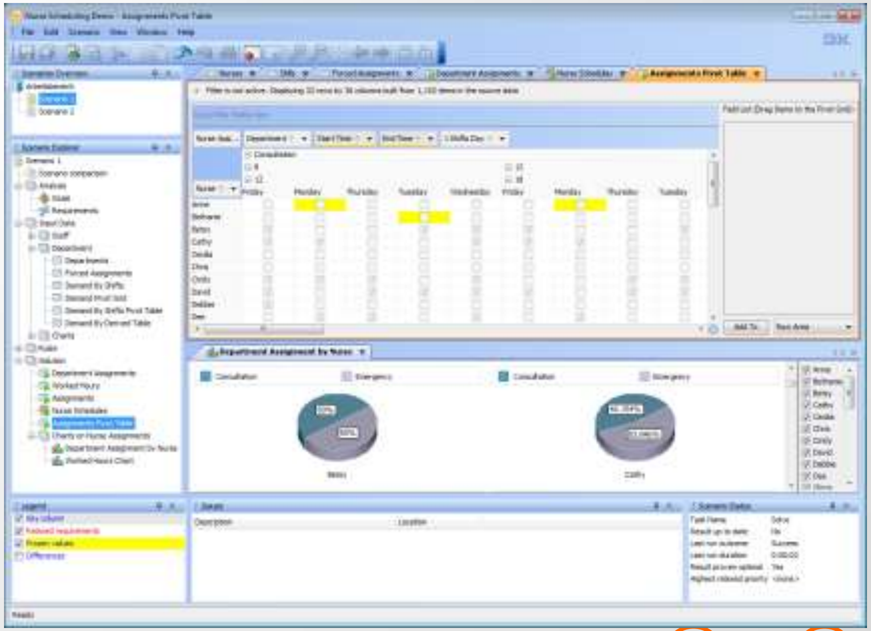
AML

Solver

Database

Analytical Software

- “Construction Kit” with different connected elements
- Use (open source) existing framework to build applications, e.g. IBM ODME



Summary

AML – A Success Story

Design Principles

- Simple, but powerful language
- Open interfaces
- Different layers

Model Deployment

- Is optimization special?
- Provide cutting edge technology
- Don’t lock developers and users into a certain environment

Thank You

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