A distributed Optimization Bot/Agent Application Framework for GAMS Models

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Implementation of Prototype by Girish Garg

GAMS Development Corp. | *GAMS Software GmbH* | *www.gams.com*

Agenda

- Introduction
- Model Building and Application Building
- A Prototype
- Summary and Outlook

Company

- *Roots: World Bank, 1978 – 1987 Initial product*
- Went commercial in 1987
- GAMS Development Corp. (USA), GAMS Software GmbH (Germany)
- 2016: New management team
- Software Tool Provider

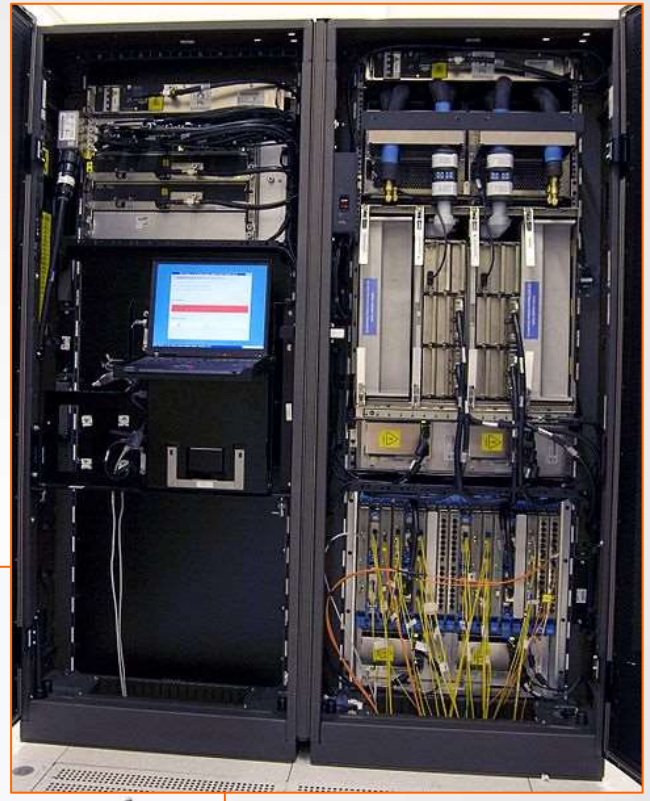
GAMS at a Glance

- Pioneered Algebraic Modeling Languages
- Robust, scalable state-of-the-art algebraic modeling technology for complex, large-scale optimization
- Open architecture and uniform interface to all major commercial and academic solvers (30+ integrated)
- Evolution through more than 25 years of R&D and user feedback, maturity through experience and rigorous testing

Change in Focus: ”Ages Ago”

Computation

- *Constraints:*
  - *Algorithms*
  - *Hardware*
  - *Modeling Technology*
- ***User: Left out***



```
ROWS
 N  COST
 L  LIM1
 G  LIM2
 E  MYEQN
COLUMNS
    XONE      COST          1   LIM1          1
    XONE      LIM2          1
    YTWO      COST          4   LIM1          1
    YTWO      MYEQN        -1
    ZTHREE    COST          9   LIM2          1
    ZTHREE    MYEQN         1
RHS
    RHS1      LIM1          5   LIM2         10
    RHS1      MYEQN         7
BOUNDS
 UP BND1      XONE          4
 LO BND1      YTWO         -1
 UP BND1      YTWO          1
```

GAMS

Change in Focus: Past → Now (1)

Algorithms / Hardware

Progress in LP: 1988—2004

(Operations Research, Jan 2002, pp. 3—15, updated in 2004)

- Algorithms (*machine independent*):

  Primal *versus* best of Primal/Dual/Barrier 3,300x

- Machines (workstations →PCs): 1,600x
- NET: Algorithm × Machine 5,300,000x

  (2 months/5300000 ~= 1 second)

Robert E. Bixby
Gurobi Optimization & Rice University

Change in Focus: Past → Now (2)

Modeling Technology

- *Algebraic Modeling Languages (AML)*
  - *Simplified model development & maintenance*
  - *Increased productivity tremendously*
  - *Made mathematical optimization available to a broader audience (domain experts)*
  - *2012 INFORMS Impact Prize*
- *Constraint: Modeling Skills*

- ***User: Involved***

C:\Users\Franz\Documents\gamsdir\projdir\trnsport.gms

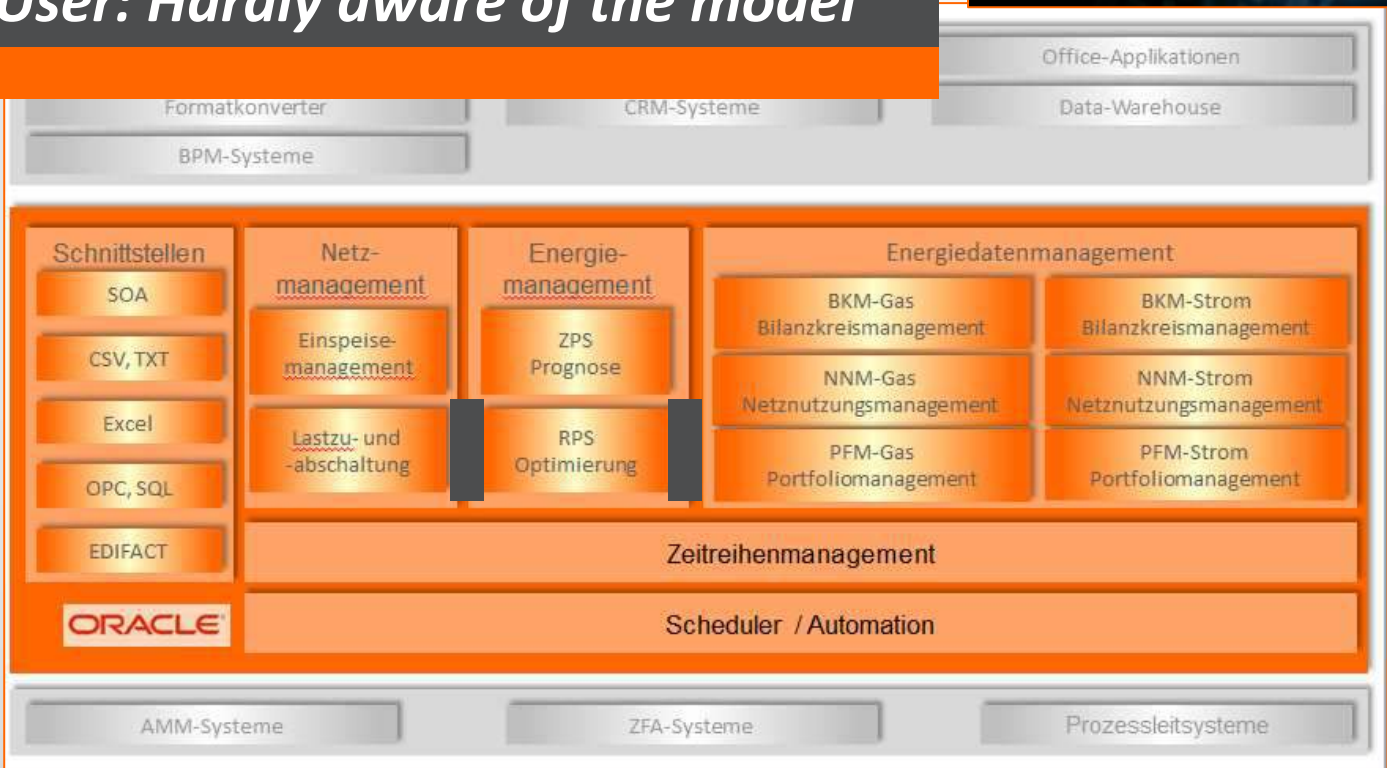
a.inc | trnsport.gms | trnsport.lst

```
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 t
            c(i,j)  transport cost in thousands of d
Variables   x(i,j)  shipment quantities in cases
            z       total transportation costs in th
Positive Variable x ;
Equations   cost        define objective function
            supply(i)   observe supply limit at plant
            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/ ;
$include data.inc
c(i,j) = f * d(i,j) / 1000 ;
Solve transport using lp minimizing z ;
Display x.l, x.m ;
```

Change in Focus: Now → Future

Application Building

- *Models (small) Part of Applications*
- *New Constraint: Integration Skills*
- ***User: Hardly aware of the model***



GAMS

Modeler's Perspective

C:\Users\franz\Documents\gamsdir\projdir\cutstock.gms

cutstock.gdx | cutstock.gms | cutstock.lst

```
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));
```

- Problem class
- Algorithm / Algebra
- Data
- Solver
- Solution

```
* pattern that might improve the master model found?
   if(z.l < -0.001,
      aip(i,pi) = round(y.l(i));
      pp(pi) = yes; pi(p) = pi(p-1);
   else
      done = 1;
```

No active process

dice | cutstock

```
Reading data...
Starting Cplex...
Tried aggregator 1 time.
MIP Presolve eliminated 2 rows and 2 columns.
Reduced MIP has 3 rows, 5 columns, and 7 nonzeros.
Reduced MIP has 0 binaries, 5 generals, 0 SOSs, and 0 indicators.
Presolve time = 0.00 sec. (0.01 ticks)
Found incumbent of value 517.000000 after 0.00 sec. (0.02 ticks)
Probing time = 0.00 sec. (0.00 ticks)
Tried aggregator 1 time.
Presolve time = 0.00 sec. (0.00 ticks)
Probing time = -0.00 sec. (0.00 ticks)
MIP emphasis: balance optimality and feasibility.
MIP search method: dynamic search.
Parallel mode: none, using 1 thread.
Tried aggregator 1 time.
No LP presolve or aggregator reductions.
Presolve time = -0.00 sec. (0.00 ticks)

Iteration      Dual Objective            In Variable           Out
     1            354.000000                xp(p2)        demand(
     2            452.750000                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
Found incumbent of value 453.000000 after 0.05 sec. (0.04 ticks)
      0     0        cutoff             453.0000      452.7500
Elapsed time = 0.05 sec. (0.04 ticks, tree = 0.00 MB, solutions =
```

Close | Open Log | Summary only | Update

Application Developer's Perspective

- IT (Software) Driven
- Software Architecture, OO-Design, Agile Development , Tiers, Components, Encapsulation, Classes, Data Access Layer,..

- Mathematical Optimization: (Maybe) Limited Knowledge / Interest

Different Communities

Analytic Professionals

- INFORMS 2017: 12,500+ members (GOR: 1,350)
- 91,300 OR analysts (2014, US Bureau of Labor Statistics)

- Niche Market: Mathematical Programming
  - Few standards, slow progress (in certain areas)
  - Active Academic Research Area

- Certification: Certified Analytics Professional (CAP) introduced in 2013

CERTIFIED ANALYTICS PROFESSIONAL

Different Communities

Software Developers

- 11 Million+ Software Developers worldwide (2014, IDC)
- Many and rapidly changing IT environments (Web, Cloud, Mobile, …)
- Certifications for IT professionals:
  - Essential
  - Plenty

PCMag UK | Amazon Web Services | Feature

The 7 Highest-Paying IT Certifications of 2017

BY JUAN MARTINEZ 7 APR 2017, 8:05 P.M.

Show your mettle by getting one of these top-paying IT certifications.

1.2K shares

Possible Issues

- Different Lifecycles for Applications and Models
- "*Optimization takes longer than one is willing to wait, and will eventually fail*"
- Quality of Data
- Generalist (domain expert and modeling expert and IT expert) versus Team of Specialists
- "New" Application or Integration

Application Building for AML

Some Approaches

Integration with Analytical Software

- "Top-Down" - Add AML to existing analytical software systems with "large" user base, e.g. MATLAB or SAS
- "Bottom-Up" - Add GUI-builder / Application Framework to AML with "small" user base, e.g.: AIMMS (Pro) or FICO Xpress-Insight

Application Building for AML

Some Approaches

Integration with Programming Language

- "Top-Down"- Extend existing programming language with declarative AML, e.g. : Pyomo (Python), JuMP (Julia), MS Solver Foundation (discontinued)
- "Bottom-Up" - Make it easy to embed GAMS into different (programming) environments

Seamless Integration

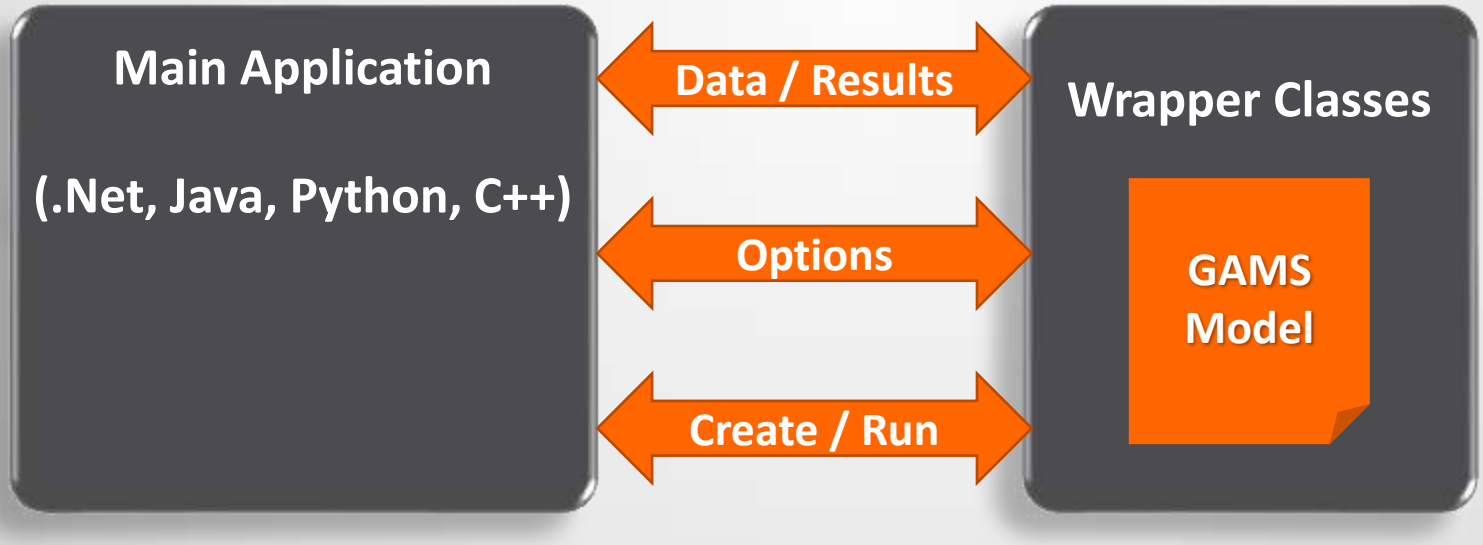
Separation of Tasks

- Use GAMS for modeling and optimization tasks
- Object oriented GAMS API connects GAMS to other environments to build Applications
  - Programming languages
  - Smart Links to Databases, Spreadsheets, Matlab, R,…
- .Net, Java, Python, C++ (open source)
- Communication through Memory or Files

OO-API: Encapsulation of GAMS Model

Simple Interface to interact with GAMS

- Classes to communicate input data and results
- Classes to change options like the solver to use
- Classes to create, run, and control model instance(s)

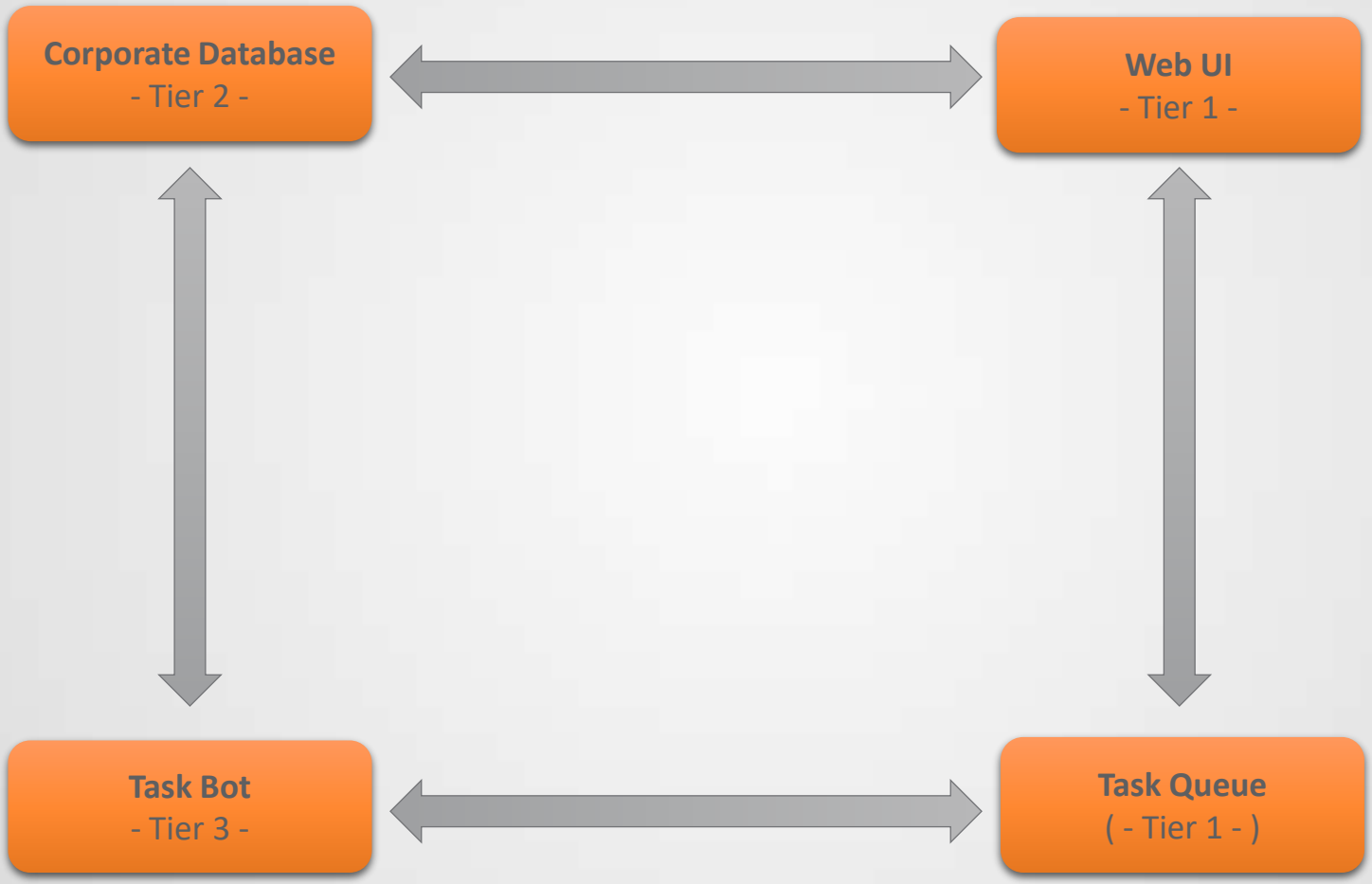


Task At Hand

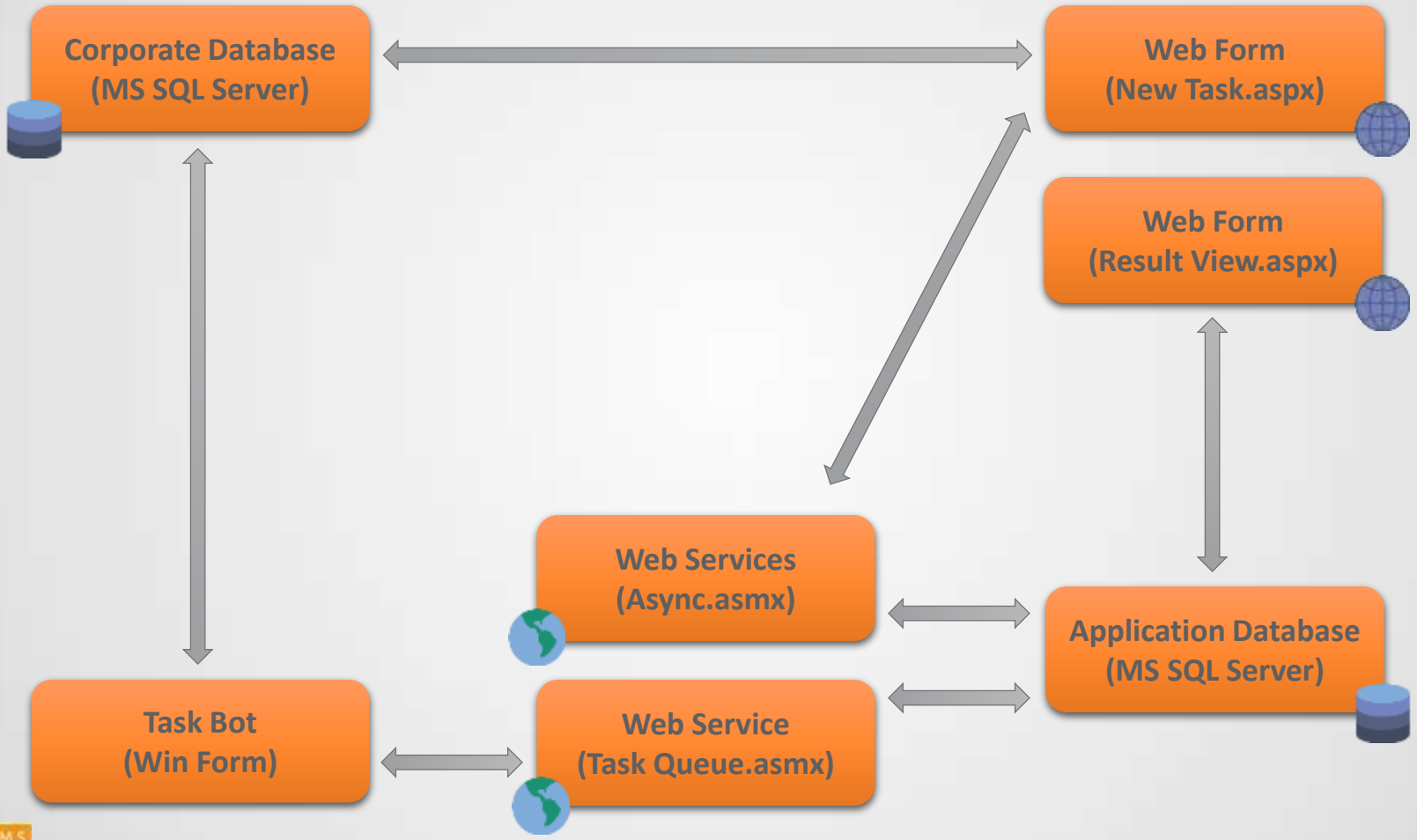
Develop Prototype of a distributed Multi-Tier Application with a Multi-User Web Interface

- Application connects GAMS Model to Databases and Web User Interface
- Bot/Agents run Model instances
- User Interface allows
  - Setup and submission of (multiple) GAMS jobs
  - Visualization of results
- Communication with GAMS through OO-API only
- .Net Application
- Application Developer has no knowledge about GAMS
- Tight Budget for Application Development

Architectural Overview



Technical Overview



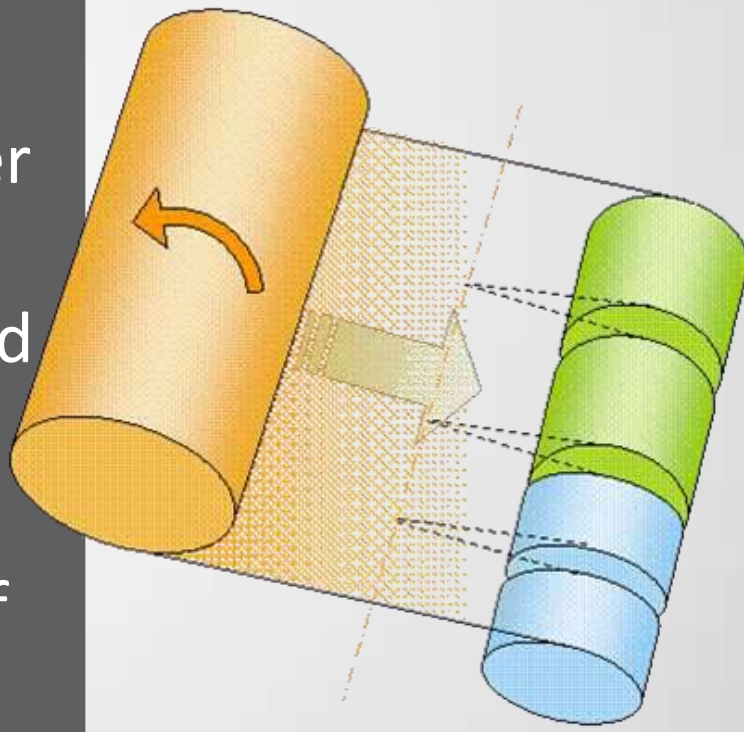
Some Features

- Asynchronous architecture: Task submission and execution are decoupled through the Task Queue
- Data Contract between Bots and Application: Common Data Structures for clear interface
- Distributed system (multiple tiers): WebUI, Databases and Bots can run on separate machines
- Scalable with multiple bot instances

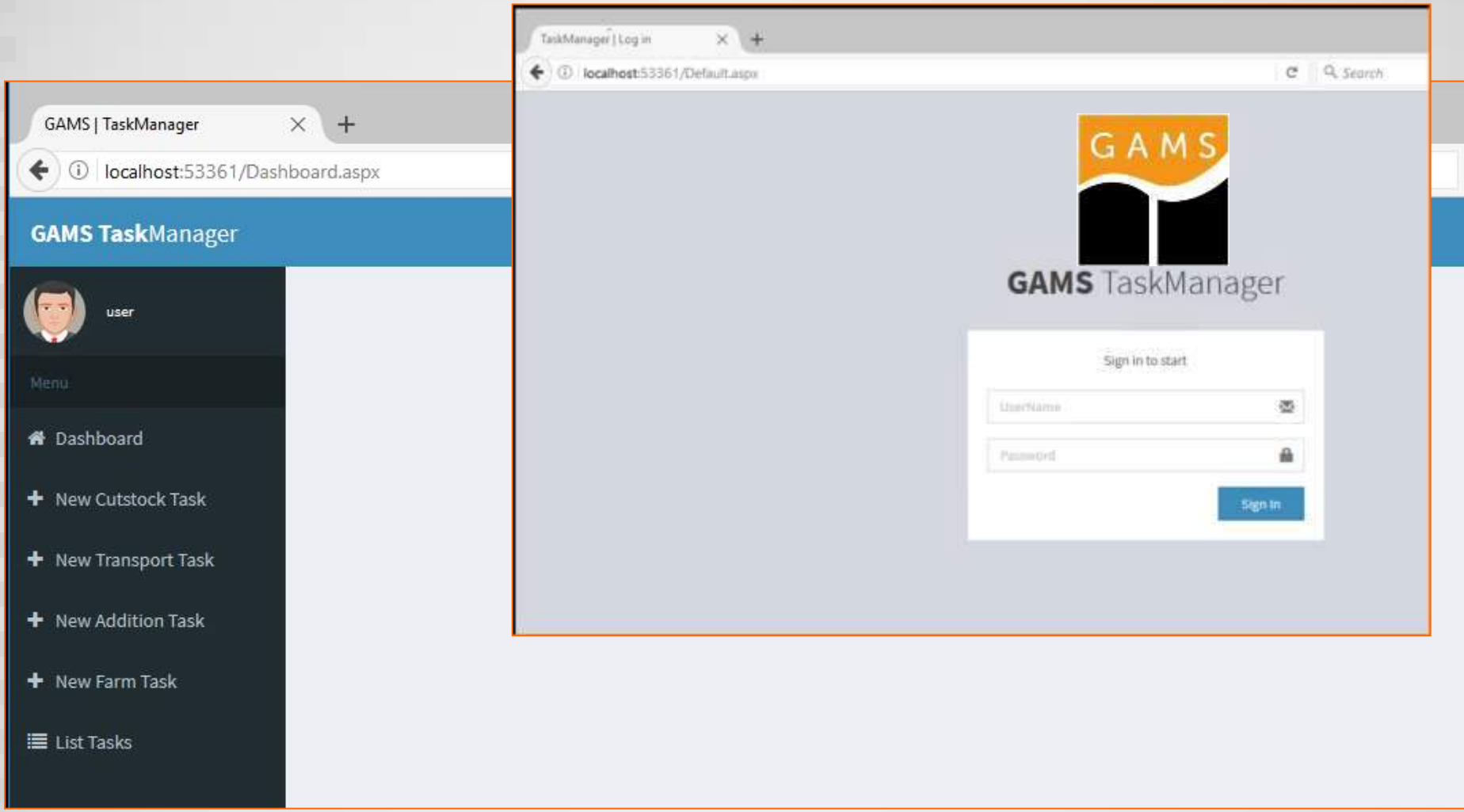
Example: Roll Cutting (cutstock.gms)

Cut paper rolls of fixed width (“raw”) into smaller portions (“finals”)

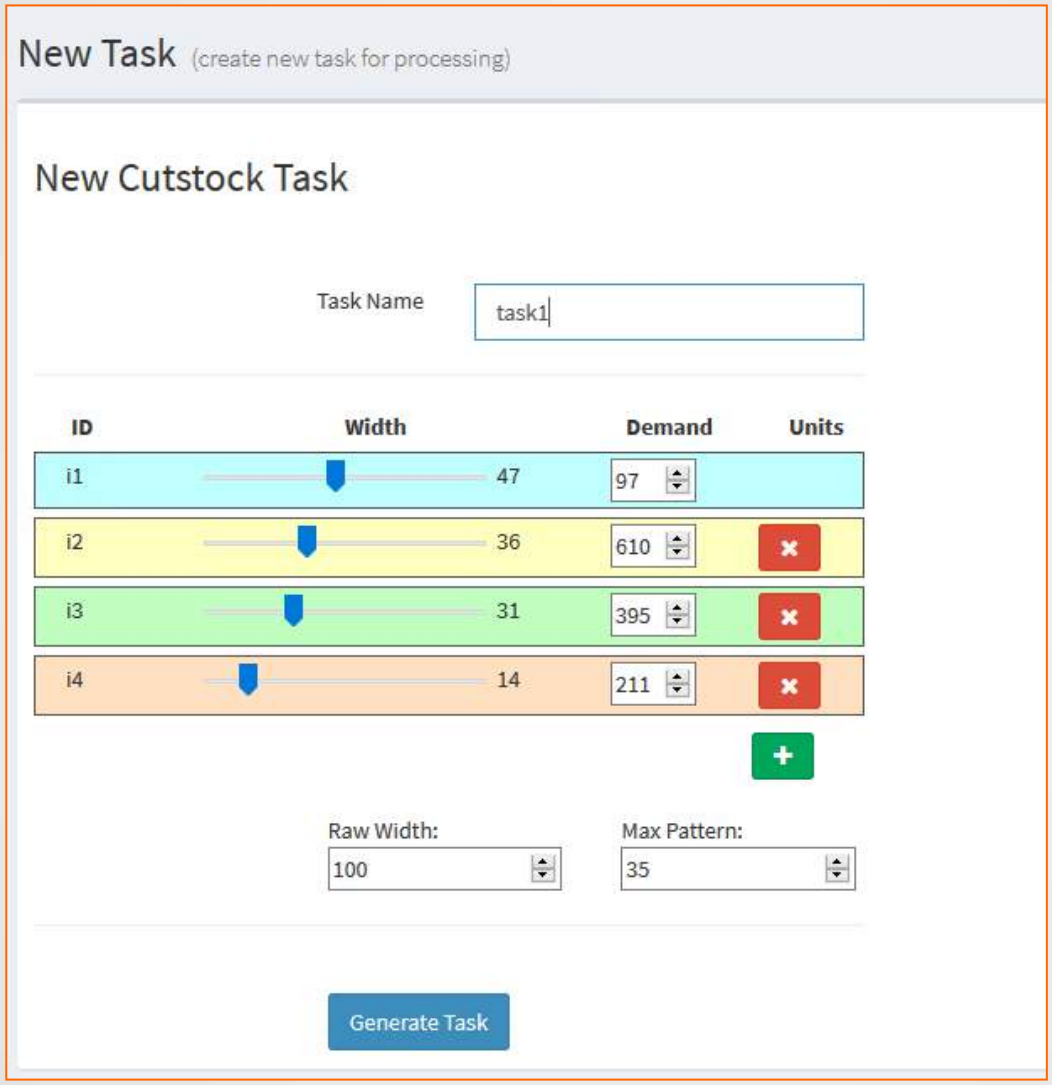
- Input:
  - Width of the raw
  - Demand: Widths and number of finals
- Objective: Minimize the required number of raws
- Output:
  - Combination and number of cuts (“patterns”)
  - Number of required raws



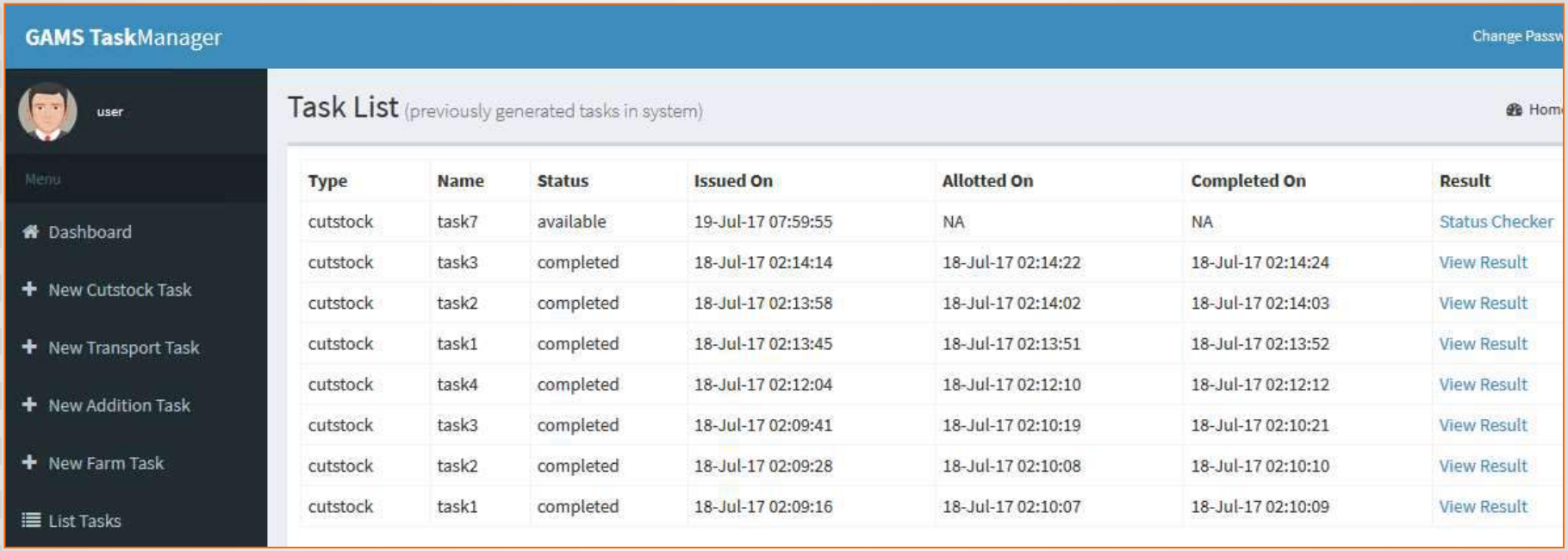
Web User Interface



Create New Cutstock Task



Task List (= Queue) and Status



Type	Name	Status	Issued On	Allotted On	Completed On	Result
cutstock	task7	available	19-Jul-17 07:59:55	NA	NA	Status Checker
cutstock	task3	completed	18-Jul-17 02:14:14	18-Jul-17 02:14:22	18-Jul-17 02:14:24	View Result
cutstock	task2	completed	18-Jul-17 02:13:58	18-Jul-17 02:14:02	18-Jul-17 02:14:03	View Result
cutstock	task1	completed	18-Jul-17 02:13:45	18-Jul-17 02:13:51	18-Jul-17 02:13:52	View Result
cutstock	task4	completed	18-Jul-17 02:12:04	18-Jul-17 02:12:10	18-Jul-17 02:12:12	View Result
cutstock	task3	completed	18-Jul-17 02:09:41	18-Jul-17 02:10:19	18-Jul-17 02:10:21	View Result
cutstock	task2	completed	18-Jul-17 02:09:28	18-Jul-17 02:10:08	18-Jul-17 02:10:10	View Result
cutstock	task1	completed	18-Jul-17 02:09:16	18-Jul-17 02:10:07	18-Jul-17 02:10:09	View Result

Tasks Results Page (1)

Task Results (task3)

Home > Tasks >

Name	task3	**IssuedOn**	18-Jul-17 02:14:14
Type	cutstock	**AllottedOn**	18-Jul-17 02:14:22
Status	completed	**CompletedOn**	18-Jul-17 02:14:24
Done By	CutstockBot01		

Input

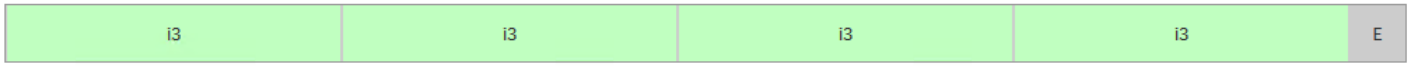
RawWidth	MaxPattern
125	35

Piece Name	Width	Demand	Color
i1	47	97	
i2	36	610	
i3	31	395	
i4	14	211	

Tasks Results Page (2)

Output

pattern 5 : **87** times



pattern 6 : **203** times

pattern 9 : **47** times

pattern 11 : **3** times

Log

New pattern! Value: -3

New pattern! Value: -2.33333333333333

New pattern! Value: -1.66666666666667

New pattern! Value: -1.25

New pattern! Value: -0.25

New pattern! Value: -0.041666666666667

New pattern! Value: -0.0220588235294117

Optimal Solution: 340

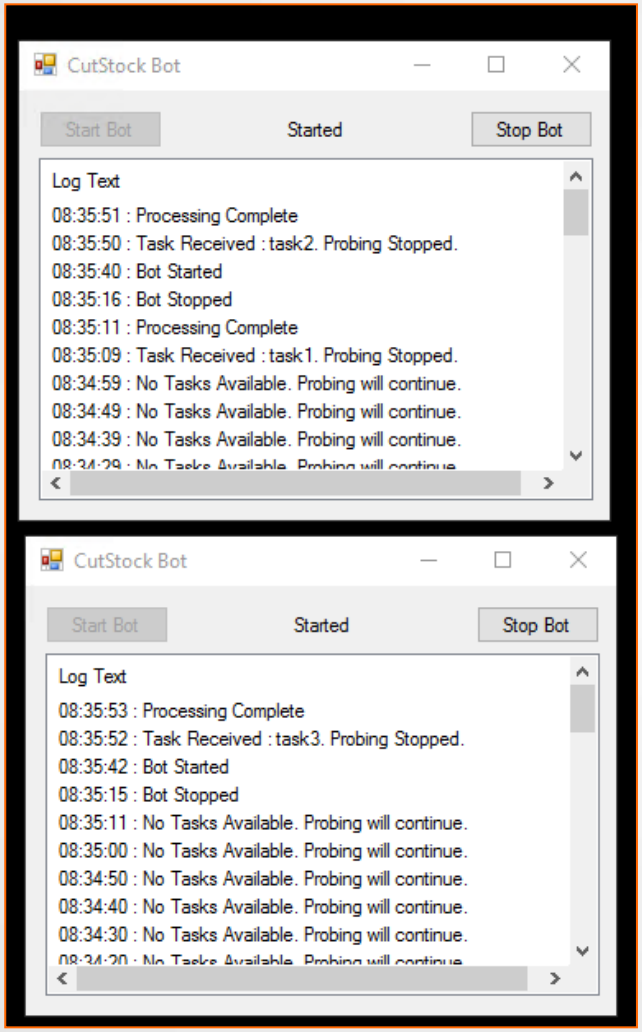
pattern 5 87 times: i3: 4

pattern 6 203 times: i2: 3 i4: 1

pattern 9 47 times: i1: 2 i3: 1

pattern 11 3 times: i1: 1 i2: 1 i4: 3

Cutstock Bots Log



Summary and Outlook

- Building Optimization Applications may be challenging

- GAMS has no preference for a specific User Interface
- OO-API makes it easy to embed GAMS models

- Optimization Bot/Agent Application Framework
  - Integrates Web UI, GAMS, task bots and queues, and databases
  - Distributed system / multiple bot instances
  - Prototype done in .Net using the .Net OO-API
  - Source code for prototype will become open source

Thank You