Bad Honnef,
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The Role and Impact of Algebraic Modeling Languages in and on Industrial Optimization

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GAMS

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

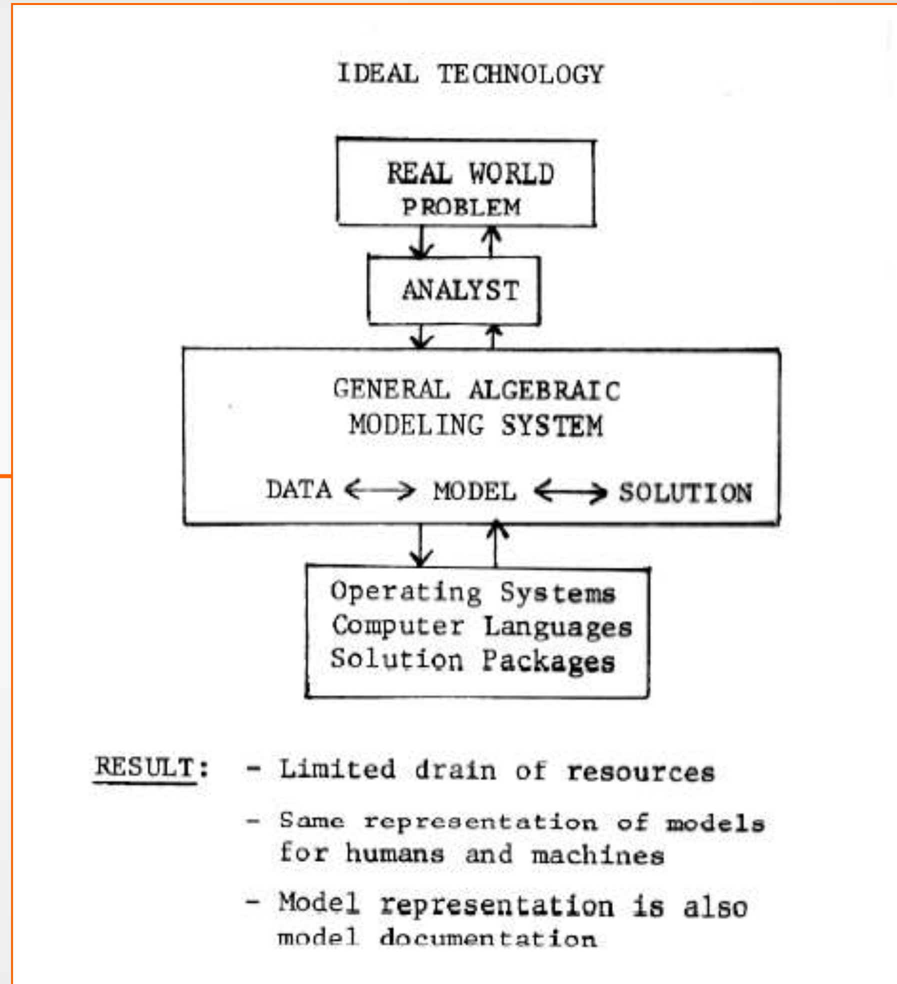
Algebraic Modeling Languages – A Success Story

GAMS – Design Principles

Some Examples

1976 - A World Bank Slide

The Vision



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

GAMS

2012 INFORMS Impact Prize

36 Years later

Originators of Algebraic Modeling Languages

AIMMS AMPL MAXIMAL GAMS LINDO SYSTEMS

Impact of Algebraic Modeling Languages

Impact of AML

1

Tremendous increased productivity, quality, reliability and maintainability

2

Simplified model development, changes, and transfer

3

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

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

Agenda

Algebraic Modeling Languages – A Success Story

GAMS – Design Principles

Some Examples

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**

Model

Platform | Solver | Data | Interface

GAMS

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

Model

Platform | Solver | Data | Interface

GAMS

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 system

Model			
Platform	Solver	Data	Interface

GAMS

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**

Model

Platform | Solver | Data | Interface

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

FICO · Gurobi Optimization · IBM · mosek · Sulum Optimization · COIN|OR

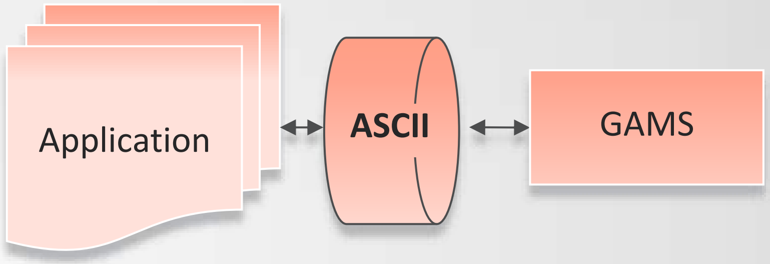
➢ Switching between solvers with one line of code

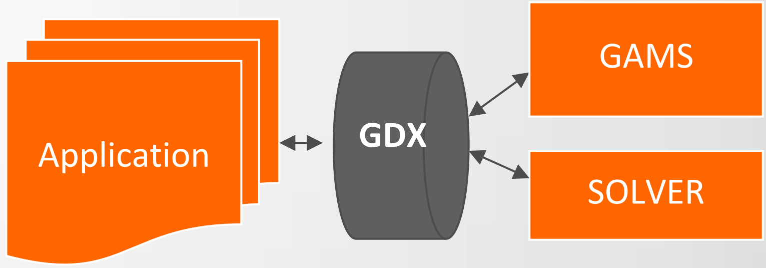
Independence of Model and Data

- **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





GAMS

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

GAMS

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

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

GAMS

Agenda

Algebraic Modeling Languages – A Success Story

GAMS – Design Principles

Some Examples

"… - asking yourself why you would do optimization in GAMS, software that looks as modern and friendly as Richard Nixon."

Customer review on Amazon.com for S. Zenios, S. Nielson, and A. Consiglio "Practical Financial Optimization: A Library of GAMS Models", Wiley, 2009

GAMS

Three (Short) Examples

1 General Dynamics – retooling the solution engines for the generation and management of efficient frontiers of multi-objective design optimization problems

2 xyz Energy Company – solving many (500+) difficult MIP models in parallel on the cloud (security issues)

3 Class Scheduling at USMA West Point – student centric scheduling of classes

General Dynamics Land Systems

ACSOM

Abrams M1A2

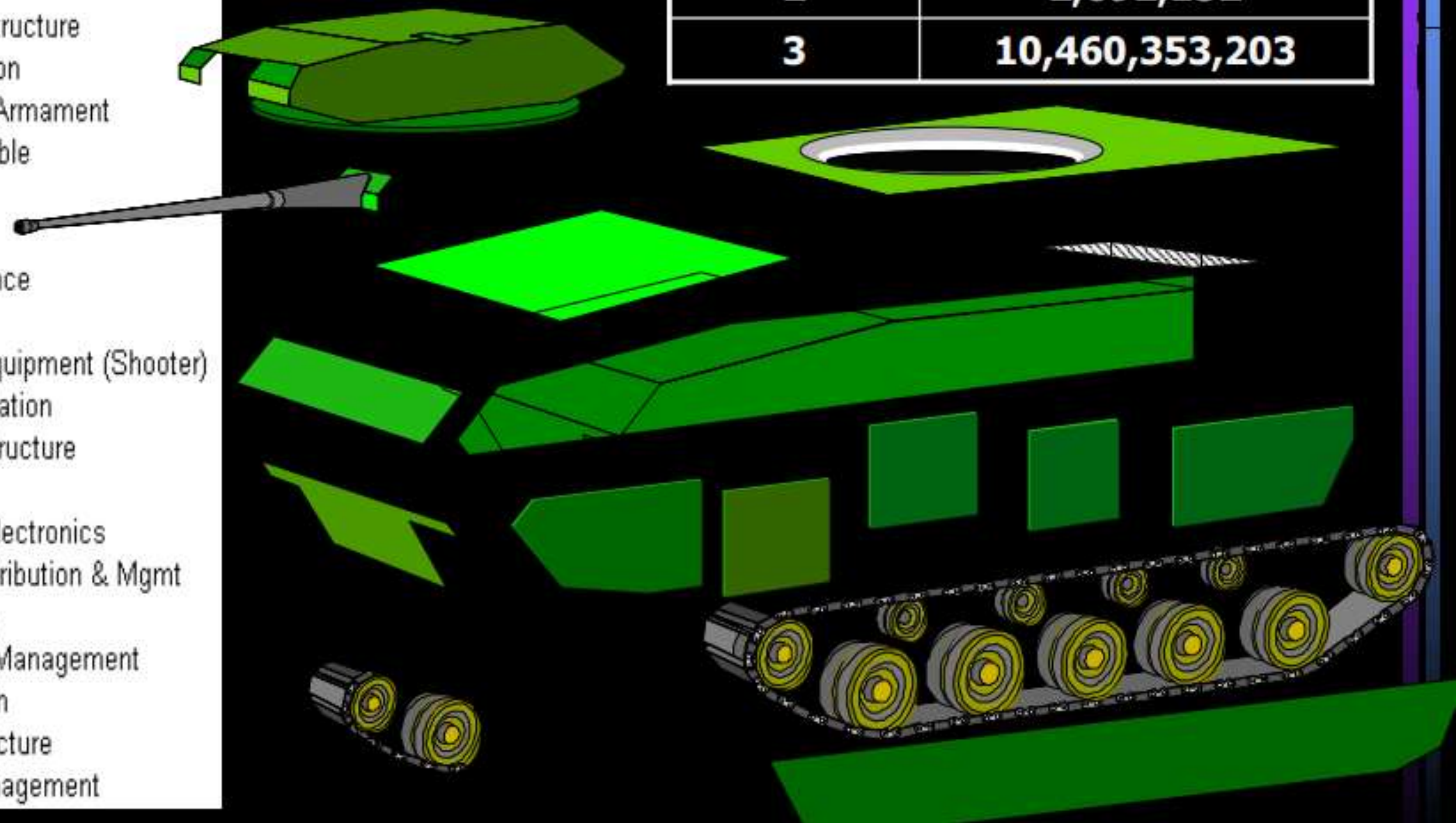
- Advanced Collaborative System Optimization Modeler
- Explore high-dimensional Pareto surface for configuration of (expensive) military vehicles
- Collaboration between:
    - General Dynamics Land Systems
    - Industrial & Systems Engineering, Wayne State University (WSU)
    - GAMS Development Corp
    - Amsterdam Optimization Group

The Whole-system Design Problem

21 SUBSYSTEMS

- AFES
- Armor
- Chassis Structure
- Crew Station
- Defensive Armament
- Dismountable
- ECS
- Fuel
- Hit Avoidance
- Lighting
- Mission Equipment (Shooter)
- Mission Station
- Mission Structure
- NBC
- Platform Electronics
- Power Distribution & Mgmt
- Propulsion
- Signature Management
- Suspension
- Turret Structure
- Water Management

Options per subsystem	Theoretically Possible Subsystem Combinations
2	2,092,152
3	10,460,353,203



Approved for Public Release, Distribution Unlimited, GDLS approved, log 2008-09, dated 03/19/08

Considers All to Make the Whole

Full Spectrum

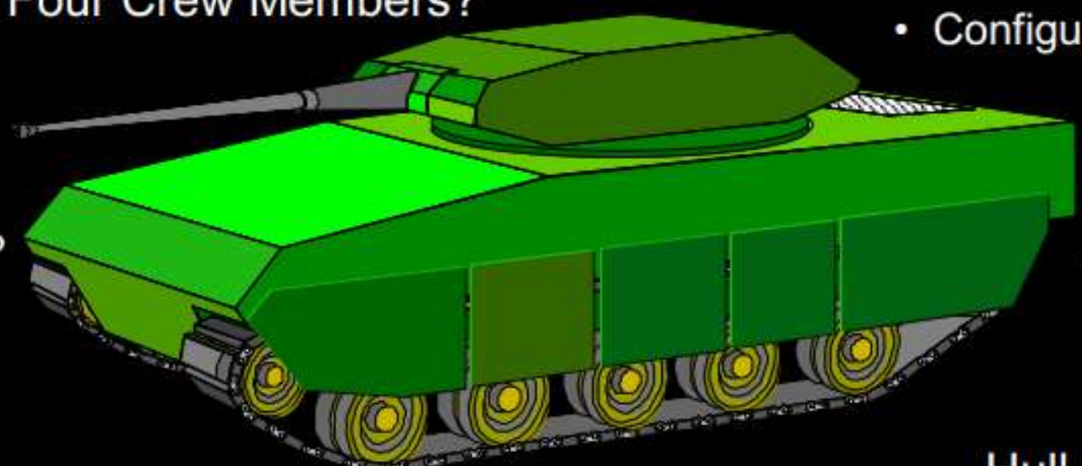
Numerous Subsystems with a multitude of options for each

Force Protection Approach?

Two, Three, Four Crew Members?

Auto loader ?

- Configuration/Approach?



Hull Material?

- Aluminum?
- Steel?
- Titanium?

Which Core Data Network?

Hull Design?

Power ?

- What Type of Engine?
- What Type Transmission?

What Type of Suspension System?

- Torsion bars?
- HSUs?

Passive?

Fully Active?

Track?

Which Servo Motor Controller Architecture?

GAMS

Utopia Point

```
alias(thisobj,obj);

loop(thisobj,
   w(obj) = 0;
   w(thisobj) = 1;

   solve mod1 using mip max ztotal;
   f_best(thisobj) = z.l(thisobj);

   solve mod1 using mip min ztotal;
   f_worst(thisobj) = z.l(thisobj);

   f_range(thisobj) = f_best(thisobj)
                         - f_worst(thisobj) ;
);
```

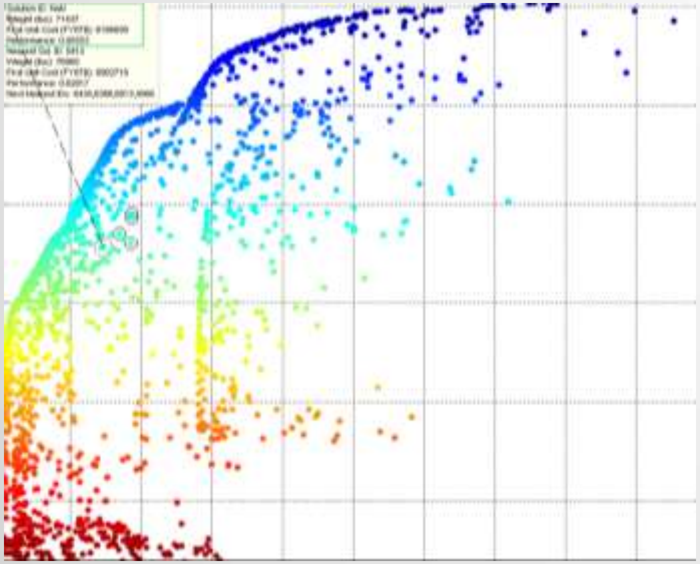
Compromise Point

```
equation
  distance 'distance to Utopia point';

variable
  sqdist  'minimum distance (normalized)';

distance..   sqdist =e=  sum(obj,
          sqr((f_best(obj)-z(obj))/f_range(obj)));

model mindist /all/;
solve mindist minimizing sqdist using miqcp;
```

How to calculate Efficient Frontier ?

Many Algorithms

- **Complete Enumeration**
- **Evolutionary Algorithms**
- **WSU Algorithms: ACE, UPSA**
- **Integer Cut**



ACSOM Algorithm

- GAMS/CPLEX solution pool to collect 1,000,000+ solutions of a small MIQP
- Compact representation of solutions
- Uses an algorithm to filter out dominated solution
  - implemented in traditional programming language with efficient data structures

Retooling of an Application

Old System

- VB.Net
- MPL (single point)
- CPLEX
- SQL throughout

New System

- GAMS (complete algorithm; streamlined design)
- GAMS .NET API for recursive ACE algorithm
- CPLEX
- Bulk SQL just once

Performance Improvements

- On the same hardware:
  - From hours and even days for large problems
  - To minutes, up to an hour

GAMS

xyz Energy Company

Massive Parallel for Large Scale MIP

- Sensitivity Analysis subject to few parameter changes
- Failures with Stochastic Optimization and Robust Optimization
- Scenario Analysis works!
- Task: Solve 1000 scenarios (MIPs, 1-2 hours) every week overnight
- Post processing (distribution of KPI) of results outside modeling system

Solving Independent Models

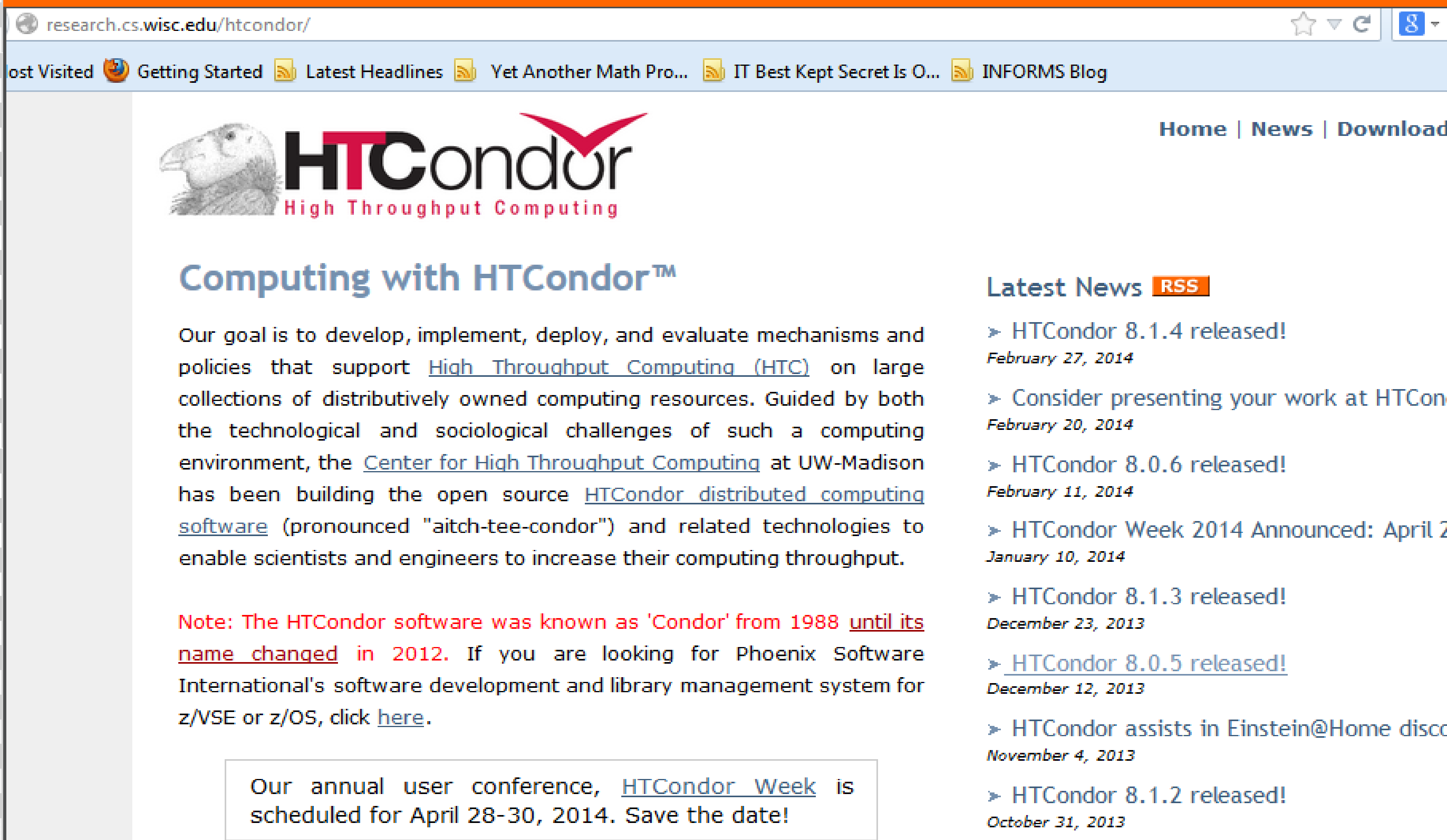
- Small Ratio of MP solution time/AML overhead
  - GUSS/Scenario Solver
- Large ratio i.e. only MP time is relevant (pre/post processing not critical)
  - Grid Facility, Gurobi/Cplex Server
- If entire model run including pre processing/MP solve/post processing is costly
  - Parallel/asynchronous execution of entire model in the cloud
  - Security issues in the cloud
    - Obfuscation

GAMS

Massively Parallel MIP

- MIP/B&C Algorithm ideal to parallelize
  - Master/Worker Paradigm (process nodes in parallel)
    - Software: FATCOP/Condor, BCP/PVM, PICO/MPI
  - Distributed MIP (sub-MIPs in parallel)
    - Software: ParaSCIP, Cplex (12.x), Gurobi (6.0)
- A-priori subdivision into n independent problems
  - Seymour problem solved that way
- Open Pit Mining (openpit in GAMS Model library)
  - Partitioning integer variables to subdivide model into into 4096 sub-problems
  - Experiments (Ferris) at UW using Condor Pool

HTCondor (previously Condor)



research.cs.wisc.edu/htcondor/

ost Visited Getting Started Latest Headlines Yet Another Math Pro... IT Best Kept Secret Is O... INFORMS Blog

HTCondor High Throughput Computing

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Computing with HTCondor™

Our goal is to develop, implement, deploy, and evaluate mechanisms and policies that support High Throughput Computing (HTC) on large collections of distributively owned computing resources. Guided by both the technological and sociological challenges of such a computing environment, the Center for High Throughput Computing at UW-Madison has been building the open source HTCondor distributed computing software (pronounced "aitch-tee-condor") and related technologies to enable scientists and engineers to increase their computing throughput.

Note: The HTCondor software was known as 'Condor' from 1988 until its name changed in 2012. If you are looking for Phoenix Software International's software development and library management system for z/VSE or z/OS, click here.

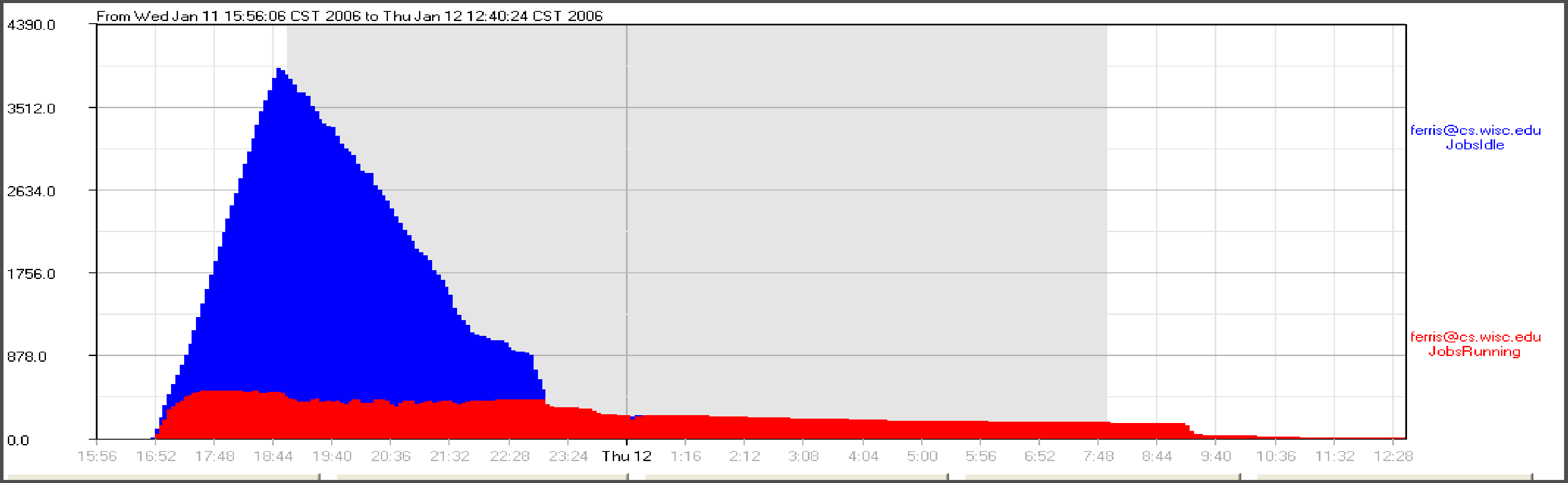
Our annual user conference, HTCondor Week is scheduled for April 28-30, 2014. Save the date!

Latest News RSS

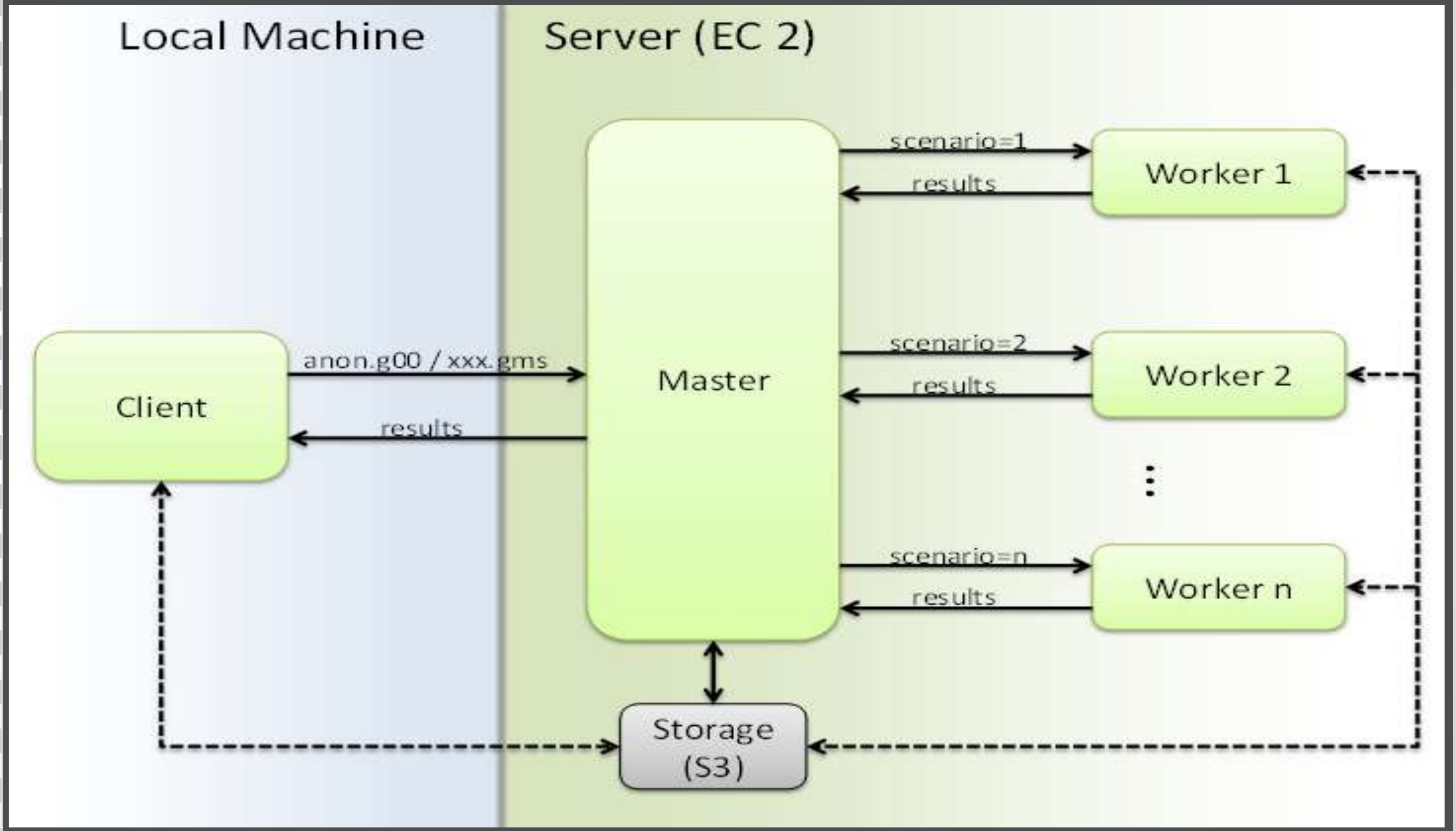
- HTCondor 8.1.4 released!
  February 27, 2014
- Consider presenting your work at HTCond
  February 20, 2014
- HTCondor 8.0.6 released!
  February 11, 2014
- HTCondor Week 2014 Announced: April 28
  January 10, 2014
- HTCondor 8.1.3 released!
  December 23, 2013
- HTCondor 8.0.5 released!
  December 12, 2013
- HTCondor assists in Einstein@Home discov
  November 4, 2013
- HTCondor 8.1.2 released!
  October 31, 2013

Results for 4096 MIPS on HTCondor

- Submission started Jan 11,16:00
- All jobs submitted by Jan 11, 23:00
- All jobs returned by Jan 12, 12:40
  - 20 hours wall time, 5000 CPU hours
  - Peak number of CPU's: 500



AWS Cloud Setup at xyz Company



Configure the Worker Instance

- Standard EC2 Linux image

Amazon Linux
Free tier eligible
Amazon Linux AMI 2013.09.2 - ami-bba18dd2 (64-bit) / ami-d7a18dbe (32-bit)
The Amazon Linux AMI is an EBS-backed, PV-GRUB image. It includes Linux 3.4, AWS tools
Root device type: ebs   Virtualization type: paravirtual

- Prepare mounting the S3 bucket on instance start up

```
sudo cd /usr/share
sudo mkdir s3fs && cd s3fs
sudo wget http://s3fs.googlecode.com/files/s3fs-1.63.tar.gz
sudo tar -xvzf s3fs-1.63.tar.gz
sudo yum update all
sudo yum install gcc libstdc++-devel gcc-c++ fuse fuse-devel curl-devel libxml2-devel openssl-devel mailcap
cd s3fs-1.63
sudo ./configure  --prefix=/usr
sudo make
sudo make install
```

- Install GAMS
- Starting the Python xmlrpc server on start up
- Add the following lines to /etc/rc.d/rc.local

```
s3fs clientservertest /mys3bucket
python /mys3bucket/gams_daemon.py &
```

mount the S3 bucket
start the daemon with the RCP server

GAMS

RPC Server – Run at Machine Start Up

- Start of server

```
server = SimpleXMLRPCServer.SimpleXMLRPCServer(("0.0.0.0", 8080))
server.register_function(spawn)
server.register_function(get_result)
server.register_function(is_done)
server.serve_forever()
```

- Asynchronous run of GAMS Job

```
def spawn(scen):
    t = threading.Thread(target=run_gams, args=(scen + 1,))
    t.start()
```

- GAMS OO API to control GAMS Job

```
def run_gams(scen):
    ws = GamsWorkspace(system_directory=sysdir)
    cp_from = ws.add_checkpoint('/mys3bucket/indus89a')
    cp_to   = ws.add_checkpoint('/mys3bucket/' + str(scen) + '_result')
    job = ws.add_job_from_string(get_model_text(), checkpoint = cp_from)
    opt = ws.add_options()
    opt.defines["scennumber"] = str(scen)
    opt.license = '/mys3bucket/gamslice.txt'
    job.run(opt, checkpoint=cp_to)
```

Submitter - Managing EC2 instances

- Start instances

```
# get EC2 connection and EC2 image
conn = EC2Connection(access_key_id, secret_access_key)
image = conn.get_all_images([image_id])
```

```
# start n instances
instances = image[0].run(min_count=n, max_count=n,
                         security_groups=["All Incoming"],
                         instance_type='t1.micro').instances
```

- Check status

```
for s in scen:
  instances[s].update()
  if instances[s].state == "running":
```

- Terminate instances

```
# shut down all machines after global time out has expired
for s in scen:
  instances[s].update()
  if instances[s].state not in ["shutting-down", "terminated"]:
    instances[s].terminate()
```

Submitter - Communicating via RPC

- Establish connection

```
server = xmlrpclib.Server("http://" + instances[s].ip_address + ":8080",
                          transport=TimeoutTransport())
servers[s] = server
```

- Call functions provides by the RPC server
  - Start job on server

```
server.spawn(s)
print "Scenario " + str(s+1) + ": Job was spawned successfully."
```

  - Check status and collect results

```
if servers[s].is_done():
  results[s] = servers[s].get_result()
  print "Scenario " + str(s+1) + ": Getting results and terminating instance"
```

GAMS

Protecting IP and Sensitive Data

- Obfuscate or hide sensitive information
  - Extrinsic function libraries
  - External Equations
  - Secure work files
  - Encrypted source files
  - Obfuscated files
    - change all the names and other documentation related to a specific model run

Obfuscated Model - Example

- GAMS Model Library: indus89 + scenario data

```
Set demandscen;
Parameter demandfactor(demandscen,cq);
$gdxin demandfactor
$load demandscen demandfactor
loop(demandscen$(ord(demandscen)=%scennumber%),
  demand(z,cq) = demand(z,cq)*demandfactor(demandscen,cq));
```

- Create obfuscated save file (compile only)
  - gams indus89 action=compile so=indus89A
- Send to cloud and execute
  - gams runscn –scennumber=n r=indus89A s=n
- Copy save files 1,...,n back and create named results
  - gams result –scennumber=n r=n rn=indus89
- Merge results (e.g. gdxmerge)
  - gdxmerge *_result.gdx

Original

i	SET	1
j	SET	1
a	PARAM	1
b	PARAM	1
d	PARAM	2
f	PARAM	0
c	PARAM	2
x	VAR	2
z	VAR	0
cost	EQU	0
supply	EQU	1
demand	EQU	1
transport	MODEL	0

NUM	UEL
1	seattle
2	san-diego
3	new-york
4	chicago
5	topeka

Obfuscated

A	SET	1
B	SET	1
C	PARAM	1
D	PARAM	1
E	PARAM	2
F	PARAM	0
G	PARAM	2
H	VAR	2
I	VAR	0
A001	EQU	0
A00001	EQU	1
A00002	EQU	1
A0000001	MODEL	0

NUM	UEL
1	"!!!!!!
2	"!!!!!!!!
3	"!!!!!!!
4	#!!!!!!
5	"!!!!!

Class Scheduling at USMA

- 1999:
  - Class Scheduling at United States Military Academy, West Point, NY, USA
  - Soon after Term End Exam Scheduling (TEE) at USMA

" … each student's daily activities are a carefully regimented balance of academic, military, and physical requirements."

- 2014:
  - Applications are alife and kicking
  - New UI & computing platform

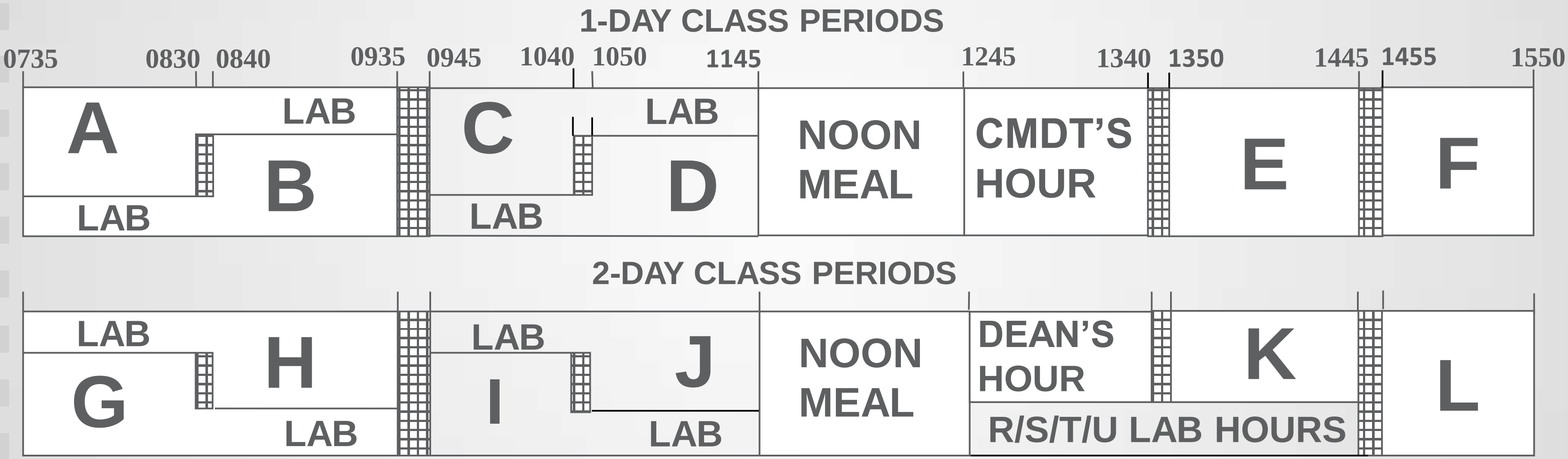
USMA is Different

- Technically
  - Day1/day2 schedule
  - Special rules (e.g. < 30% athletes in class)
- Scheduling around the cadets needs
  - No conflicting activities
  - Individual schedule of activities is compliant to vast catalogue of business rules
- Proper planning

OFFICE OF THE DEAN
UNITED STATES MILITARY ACADEMY

AUGUST 1999
(EDITION OF AUG 98 IS OBSOLETE)

ATTENDANCE PERIODS



1-DAY/2-DAY SCHEDULE: AY 99/00

LEGEND

INDICATES A or B SATURDAY

DATE — 1 — A — 2-12 — R — LESSON NUMBER FOR 40 LESSON COURSES

1-DAY or 2-DAY

R/S/T/U FIXED LAB SCHEDULED IN DEANS HOUR /K HOUR

AUGUST 1999

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
1	2	3	4	5	6	7
8	9	10 REORGANIZATION WEEK	11	12	13	14
15	16 1st Sem Begins 2-1	17 1-1	18 2-2	19 1-2	20 2-3	21 B RING WEEKEND
22	23 1-3	24 2-4 R	25 1-4	26 2-5 S	27 1-5	28 A/C
29	30 2-6 T	31 1-6				

SEPTEMBER 1999

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
			1 2-7	2 1-7	3 2-8 U	4 B
5	6 LABOR DAY (No Classes)	7 1-8	8 2-9 R	9 1-9	10 2-10 S	11 A/D HOME FOOTBALL WAKE FOREST
12	13 1-10	14 2-11 T	15 1-11	16 2-12 U	17 1-12	18 A/C AWAY FOOTBALL TULANE
19	20 2-13 R	21 1-13	22 2-14	23 1-14	24 2-15 S	25 A/D HOME FOOTBALL BALL STATE
26	27 1-15	28 2-16 T	29 1-16	30 2-17 U		

OCTOBER 1999

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
					1 1-17	2 A/D HOME FOOTBALL E CAROLINA
3	4 2-18 R	5 1-18	6 2-19 S	7 1-19 HOME FOOTBALL LOUISVILLE	8 PLEBE PARENT WEEKEND (NO CLASSES)	9 B
10 PLEBE PARENT WEEKEND	11 COLUMBUS DAY (No Classes)	12 2-20 T	13 1-20	14 2-21 U	15 1-21	16 Class Day 2-22 AWAY FOOTBALL S MISSISSIPPI
17	18 1-22	19 2-23 R	20 1-23	21 2-24 S	22 1-24	23 A/C HOMECOMING FOOTBALL NEW MEXICO
24	25 2-25 T	26 1-25	27 2-26 U	28 1-26	29 2-27 R	30 A/D
31						

NOVEMBER 1999

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
	1 1-27	2 2-28 S	3 1-28	4 2-29 T	5 1-29	6 B AWAY FOOTBALL AIR FORCE
7	8 2-30 U	9 1-30	10 2-31 R	11 VETERANS DAY (No Classes)	12 1-31	13 A/D AWAY FOOTBALL MEMPHIS
14	15 2-32 S	16 1-32	17 2-33 T	18 1-33	19 2-34 Make ahead WPPWE U	20 A/C HOME FOOTBALL HOUSTON
21 WPPWE 1930	22 1-34	23 2-35	24 1-35 COMPRESSED SCHEDULE	25 THANKSGIVING LEAVE	26	27
28 THANKS-GIVING LEAVE ENDS	29 1-36	30 2-36 R				

DECEMBER 1999

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
			1 1-37	2 2-37 S	3 1-38	4 B FOOTBALL BEAT NAVY!
5	6 2-38 T	7 1-39	8 2-39 U	9 1-40	10 2-40	11 TERM END EXAMS BEGIN
12	13	14 TERM END EXAMINATIONS	15	16	17	18
19 WINTER LEAVE BEGINS	20	21	22 WINTER LEAVE	23	24	25
26	27	28	29 WINTER LEAVE	30	31	

JANUARY 2000

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
						1 WINTER LEAVE
2 WINTER LEAVE ENDS	3	4 MILITARY INTERSESSION	5	6	7	8
9	10	11 MILITARY INTERSESSION	12	13	14	15
16	17 M.L KING'S B'DAY (No Classes)	18 2nd Term Begins 2-1	19 1-1	20 2-2	21 1-2	22 B 500TH NIGHT
23	24 2-3	25 1-3	26 2-4 R	27 1-4	28 2-5 S	29 A/C YEARLING WEEKEND
30	31 1-5					

FEBRUARY 2000

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
		1 2-6 T	2 1-6	3 2-7 U	4 1-7	5 A/C
6	7 2-8 R	8 1-8	9 2-9 S	10 1-9	11 2-10 T	12 A/D RMC @ RMC
13	14 1-10	15 2-11 U	16 1-11	17 2-12 R	18 1-12	19 B
20	21 PRESIDENTS DAY (No Classes)	22 2-13	23 1-13	24 2-14 S	25 1-14	26 A/D B for 1st Class 100TH NIGHT
27	28 2-15 T	29 1-15				

MARCH 2000

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
			1 2-16 U	2 1-16	3 2-17 R	4 CLASS DAY 1-17
5	6 2-18	7 1-18	8 2-19 S	9 1-19	10 2-20 T	11 A/C
12	13 1-20	14 2-21 U	15 1-21	16 2-22 R	17 1-22 COMPRESS SCHEDULE	18 SPRING LEAVE BEGINS
19	20	21	22 SPRING LEAVE	23	24	25
26 SPRING LEAVE ENDS	27 1-23	28 2-23	29 1-24	30 2-24 T	31 1-25	

APRIL 2000

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
						1 CLASS DAY 2-25
2	3 1-26	4 2-26 U	5 1-27	6 2-27 R	7 1-28	8 A/C
9	10 2-28 S	11 1-29	12 2-29 T	13 1-30	14 2-30 U	15 A/D FEE
16	17 1-31	18 2-31 R	19 1-32	20 2-32 S	21 1-33 Make ahead WPPWE	22 B
23 EASTER WPPWE 1930	24 2-33 T	25 1-34	26 2-34 U	27 1-35	28 2-35 R	29 A/C SANDHURST
30						

MAY 2000

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
	1 1-36	2 2-36 S	3 1-37	4 2-37 T	5 1-38	6 A/C
7	8 2-38 U	9 1-39	10 2-39	11 1-40	12 2-40	13 A/D
14	15	16 TERM END EXAMINATIONS	17	18	19	20
21	22 STAP BEGINS	23	24	25	26	27 GRADUATION DAY
28	29 MEMORIAL DAY CLASSES IN SESSION	30	31			

JUNE 2000

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16 STAP ENDS	17 STAP GRADUATION
18	19	20	21	22	23	24
25	26	27	28	29 RECEPTION "R" DAY	30	

Last Updated: 5 May 1999

GAMS

USMA is Different

- Technically
  - Day1/day2 schedule
  - Special rules (e.g. < 30% athletes in class)
- Scheduling around the cadets needs
  - No conflicting activities
  - Individual schedule of activities is compliant to vast catalogue of business rules
- Proper planning

GAMS

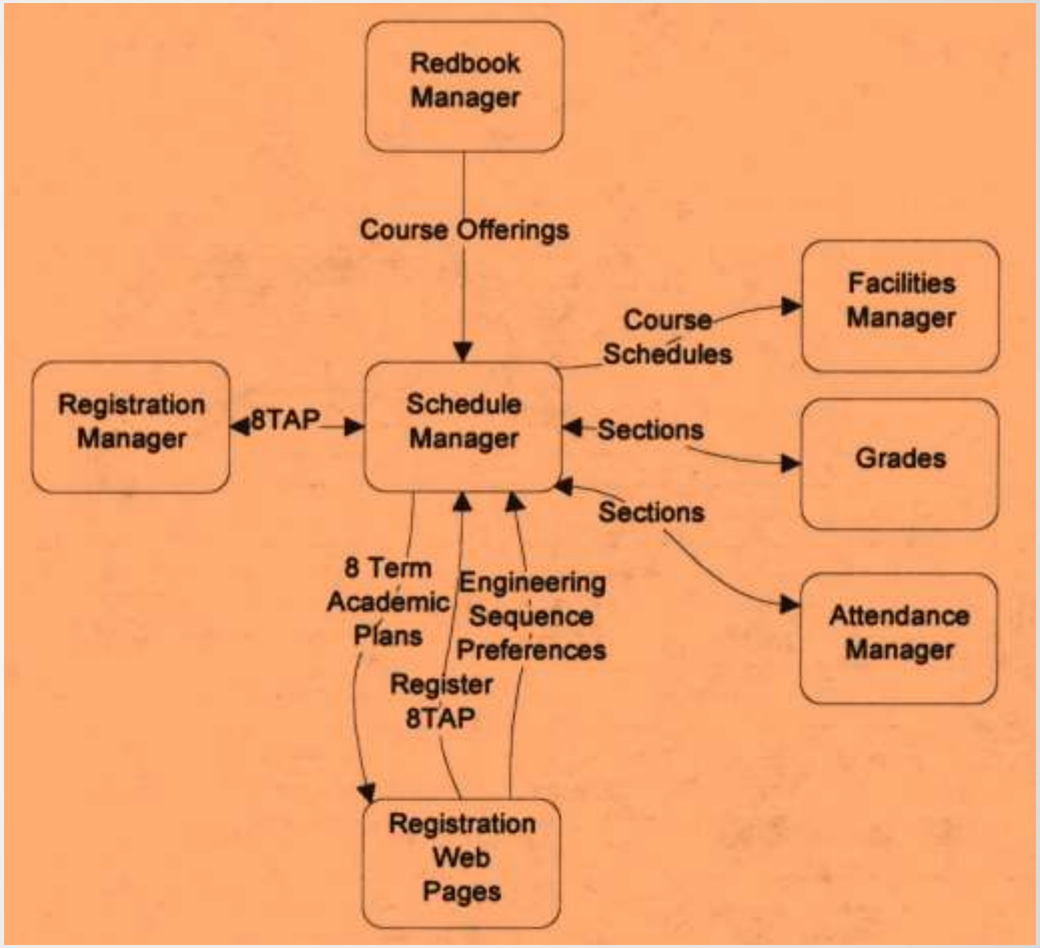
Academic Program

- 8 Term Academic Program (8TAP)
- For example, Mathematics Major: Statistics/Optimization

	4		5	6		7	8
1	PH202		ENG SEQ	ENG SEQ		ENG SEQ	ENG SEQ
2	MA206		ENG SEQ	MA363		MA386	MA476*
3	LX2XX		MA376	MA371		MA381*	**MA481***
4	SS20X		MA383	MA387		MA492D*	MA491
5	EV203		SS307	EN302		HI301	HI302
6	MA 391		PL300			LW403	

Enterprise Academy Management System

- Management of :
  - Redbook
  - Registration
  - Schedule
  - Facility
  - Attendance
  - Grades



GAMS

Academic Scheduling

Course Scheduling

- For a given set of course offerings find good schedules for all cadets.
- Scheduling preps
- Term balancing (department resources)
- Initial course offerings
- Scheduling
- Manual post scheduling

Term End Exam (TEE)

- Find good schedules for exam courses and cadets

MADN-MATH DEPARTMENT OPERATIONS - Netscape

File Edit View Go Communicator Help

Back Forward Reload Home Search Netscape Print Security Shop Stop

Bookmarks Location: http://apps/dean/dept_ops/app.cfm What's Rela

Instant Message WebMail Radio People Yellow Pages Download Calendar Channels ORD Information BTD Programs Ac Application Por

Course:

Search

Offerings

Sections

Future Terms:

Course Planner:

Planner

Next Term:

Instruction Periods:

Inst Periods

Instruction Periods Rollup:

Inst Periods

View all courses sponsored by department:

Curric Database

Main

MA104 COURSE OFFERINGS

COURSE	NBR SECT	SECT SIZE	CPBLTY	ENRLD	SEATS
MA104	52	18	936	933	3

Tight

MA104 INSTRUCTION PERIODS

COURSE	HOUR	NBR SECT	SECT SIZE	CPBLTY
MA104	AG	13	18	234
MA104	BH	13	18	234
MA104	CI	13	18	234
MA104	DJ	13	18	234

MA205 COURSE OFFERINGS

COURSE	NBR SECT	SECT SIZE	CPBLTY	ENRLD	SEATS
MA205	5	18	90	70	20

Depts

MA205 INSTRUCTION PERIODS

COURSE	HOUR	NBR SECT	SECT SIZE	CPBLTY
MA205	AG	1	18	18

GAMS

Scheduling Cadet Courses to Hours

Given course hours & capacity

MA481,AB,36	MA481,CD,18	MA481,EF,18
PE300,C,180	PE300,J,60	MA371,F,18

Given cadet's course registration

043671571,MA481
043671571,PE300

Objective: Find a *good* assignment of cadet's course requests to course hours

043671571,MA481,CD
043671571,PE300,J

Scheduling System Objectives

- Produced in a timely fashion
- Complies with ***most*** constraints/rules…
  - Individual:
    - Cadet can't be at two places at the same time
    - Course hours are balanced over Day-1, Day-2
    - Free hour
    - Cadet gets scheduled for all courses he/she has registered for
- Capacity:
  - Enrollment of course hour cannot exceed capability
  - Course enrollment of freshmen which are also athletes cannot exceed 60% of the total enrollment

GAMS

Legacy Scheduling System

- Matching algorithm based on cadet’s course registration only
- Reporting programs check schedule against **all** constraints and business rules
- Last years (1998): 80% of cadets rescheduled manually
- Time to generate schedule: 4 weeks (3 Schedulers)

An Optimization Model

$$
\begin{array}{rcll}
\min \sum_{ro} (p1_{ro} * \pi 1_{ro} & + & p2_{ro} * \pi 2_{ro}) + \sum_{c} (p3_c * \pi 3_c + p4_c * \pi 4_c) & \\
\sum_{o} x_{c,ro} & = & 1 & \text{(for all 8TAP entries)} \\
\sum_{r} x_{c,ro} & \leq & 1 + \pi 3_c & \text{(for all cadets } c \text{ for all time slots } o\text{)} \\
-\sigma - \pi 4_c \leq \sum_{ro \text{ on day-1}} x_{c,ro} - \sum_{ro \text{ on day-2}} x_{c,ro} & \leq & \sigma + \pi 4_c & \text{(for all cadets } c\text{)} \\
x_{c,ro} & = & 0 & \text{(for all } c, ro \text{ where } c \text{ has activity at } o\text{)} \\
\sum_{c} x_{c,ro} & \leq & cap_{ro} + \pi 1_{ro} & \text{(for all course hours } ro\text{)} \\
\sum_{c \text{ freshman\&athlete}} x_{c,ro} - 0.6 \sum_{c} x_{c,ro} & \leq & \pi 2_{ro} & \text{(for all course hours } ro\text{)}
\end{array}
$$

- 60,000 Variables, 500,000 Non-Zeros
- 24 hours CPLEX 6.6 and no integer solution

Problems with a MP Model

- There is no solution subject to *all* constraints/rules for real data

- What is the objective for the model?
- *Goal Programming:*
  - Relax constraints/rules by penalizing violations. Select penalties for violations: Calibration of the model.

GAMS

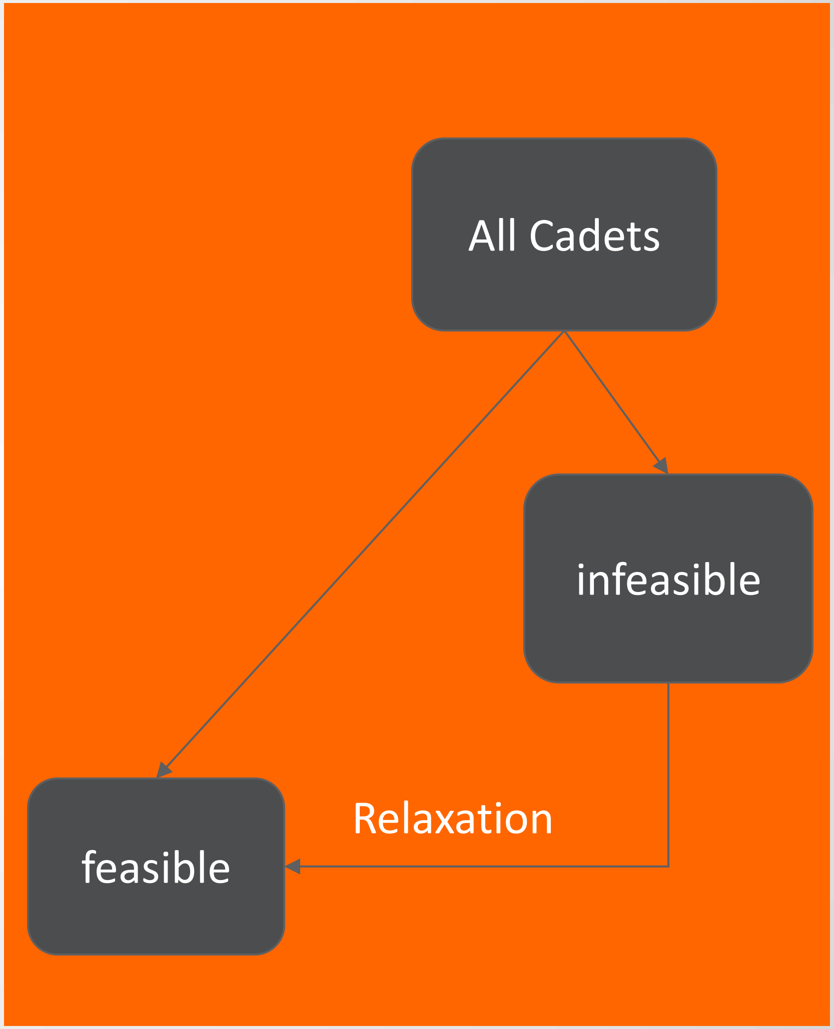
A 2-Stage Approach

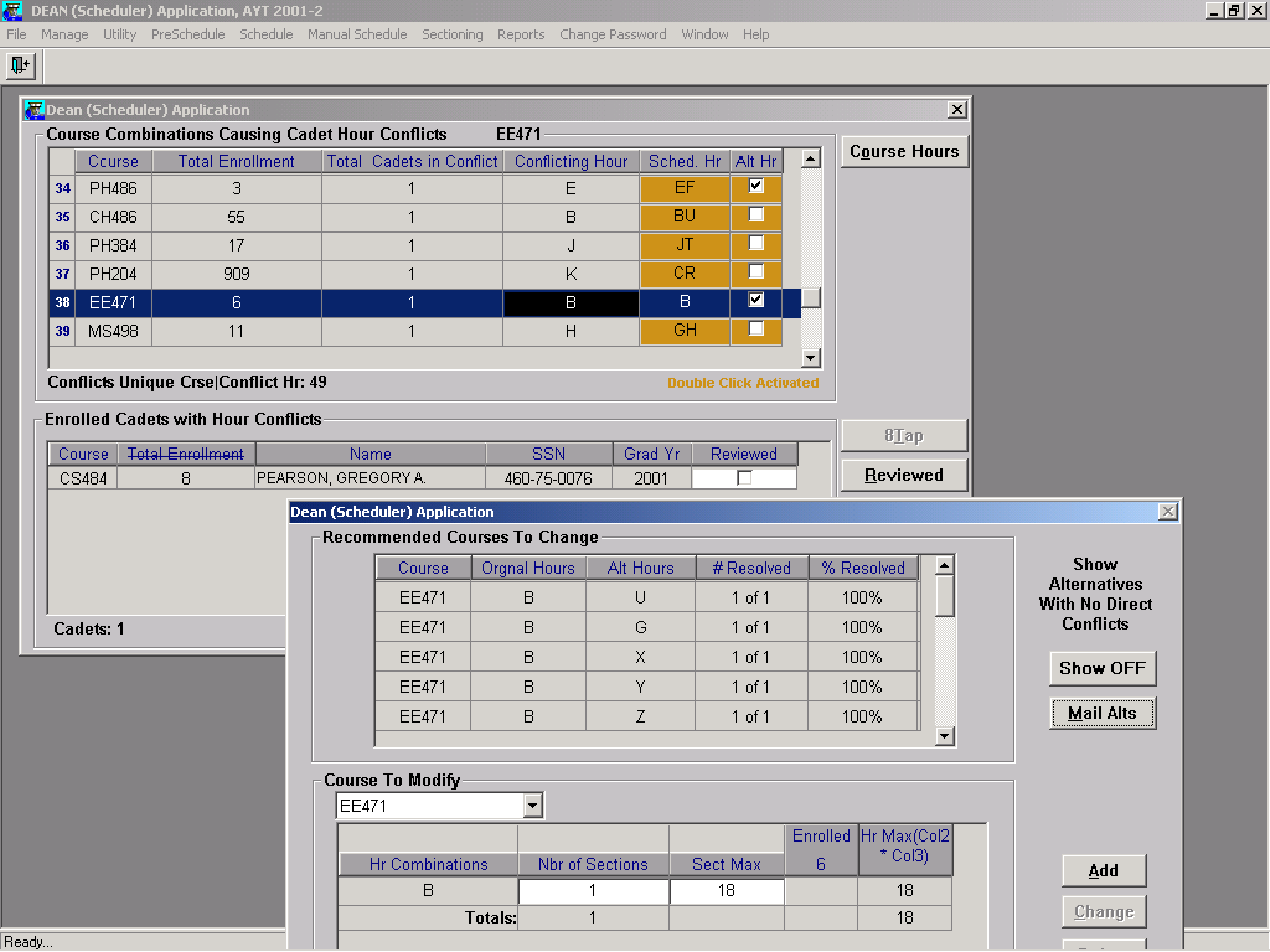
- Prescheduling
  - Filter cadets with no feasible schedule
  - Overcome infeasibility by relaxation/data changes
- Scheduling
  - All individual constraints/rules are hard constraints
  - Find assignment that does not exceed capacity (or penalize overloads)

Prescheduling

One cadet at a time

- Check feasibility
- If infeasible produce several infeasible schedules ranked by severity of infeasibility
  - Hour Conflict
  - Day – Day Balance
  - Last Hour Free
- Human intervenes




DEAN (Scheduler) Application, AYT 2001-2
File Manage Utility PreSchedule Schedule Manual Schedule Sectioning Reports Change Password Window Help
Dean (Scheduler) Application
Course Combinations Causing Cadet Hour Conflicts EE471
Course Hours
Course | Total Enrollment | Total Cadets in Conflict | Conflicting Hour | Sched. Hr | Alt Hr
34 PH486 3 1 E EF
35 CH486 55 1 B BU
36 PH384 17 1 J JT
37 PH204 909 1 K CR
38 EE471 6 1 B B
39 MS498 11 1 H GH
Conflicts Unique Crse|Conflict Hr: 49
Double Click Activated
Enrolled Cadets with Hour Conflicts
8Tap
Reviewed
Course | Total Enrollment | Name | SSN | Grad Yr | Reviewed
CS484 8 PEARSON, GREGORY A. 460-75-0076 2001
Cadets: 1
Dean (Scheduler) Application
Recommended Courses To Change
Course | Orgnal Hours | Alt Hours | # Resolved | % Resolved
EE471 B U 1 of 1 100%
EE471 B G 1 of 1 100%
EE471 B X 1 of 1 100%
EE471 B Y 1 of 1 100%
EE471 B Z 1 of 1 100%
Show Alternatives With No Direct Conflicts
Show OFF
Mail Alts
Course To Modify
EE471
Hr Combinations | Nbr of Sections | Sect Max | Enrolled 6 | Hr Max(Col2 * Col3)
B 1 18 18
Totals: 1 18
Add
Change
Ready...

GAMS

Scheduling in Batches

- Now individual constraints allow feasible schedules for all cadets (hard constraints)
- Tight Capacity of Course Hours may still result in an infeasible model:
  → Assign Overload Penalties
- Model with all cadets still *unsolvable*!

Scheduling

- Take a batch of cadets (10-30) and schedule them independent of the others
- Objective: Meet the capacity profile of the course hours (Penalize Over- and Underload)
- Example:
  - 3 course hours MA481 AB (20), CD,IJ (10)
  - Batch contains 8 cadets with request for MA481

GAMS

Results

- AY 2000/2 tested in parallel
- AY 2001/1 deployed

	Legacy System	New System
Individual Relaxations free/group/unbalanced	203/304/116	58/25/4
Capacity Overloads Courses/seats	12/54	9/21
Number of Schedulers	3	1
Time to produce Schedule	4 Weeks	1 Day

GAMS

Summary/Some Lessons Learned

- Know what you can add to a project (modeling, optimization, algorithms)
- For successful application know more than math/modeling or work with competent people that know their stuff
- Use as much off-the-shelf products AML, Excel, Matlab, R, …
- Visualization of results

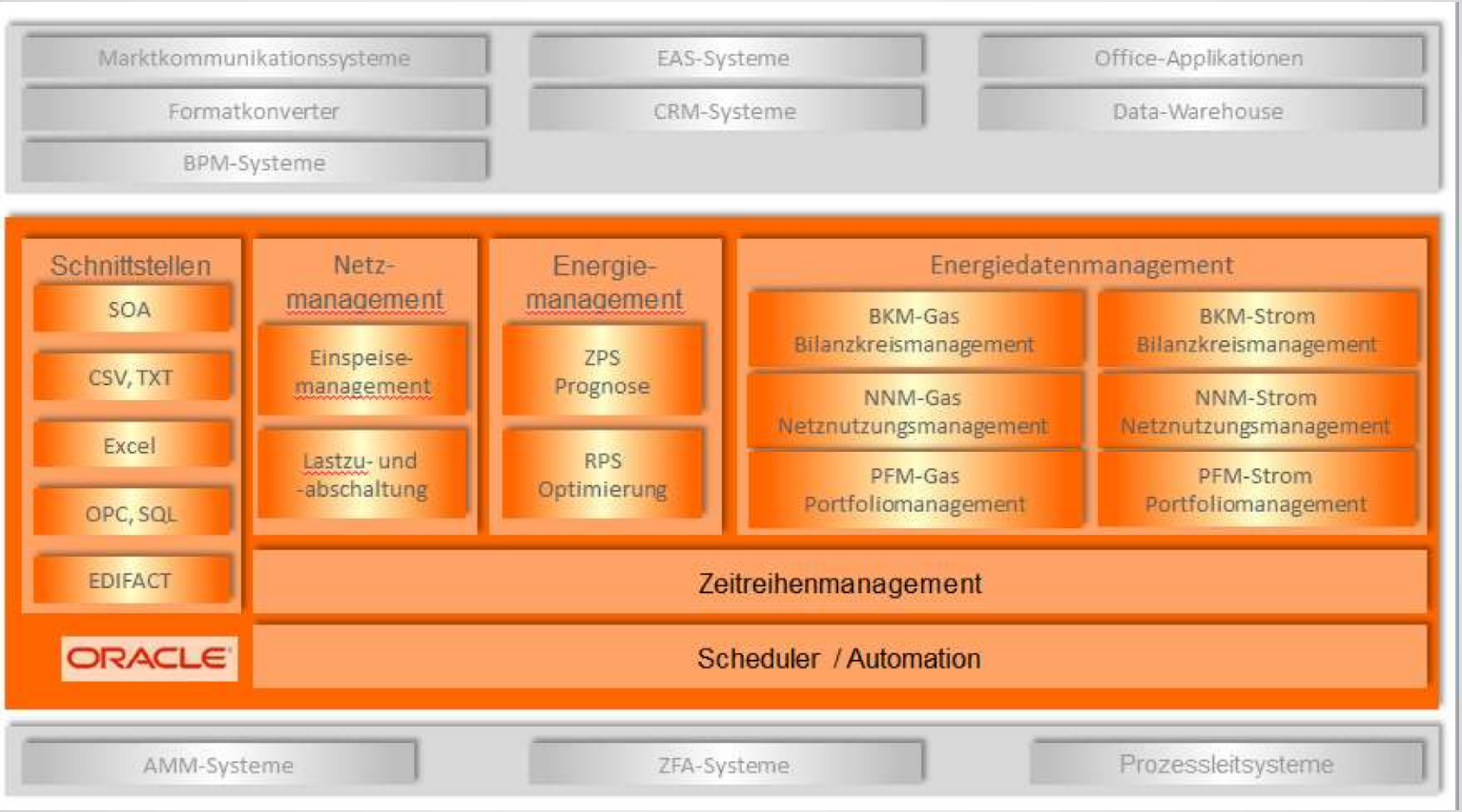
GAMS

EMS-EDM Prophet

EMS-EDM PROPHET®
Energie- und Energiedatenmanagement

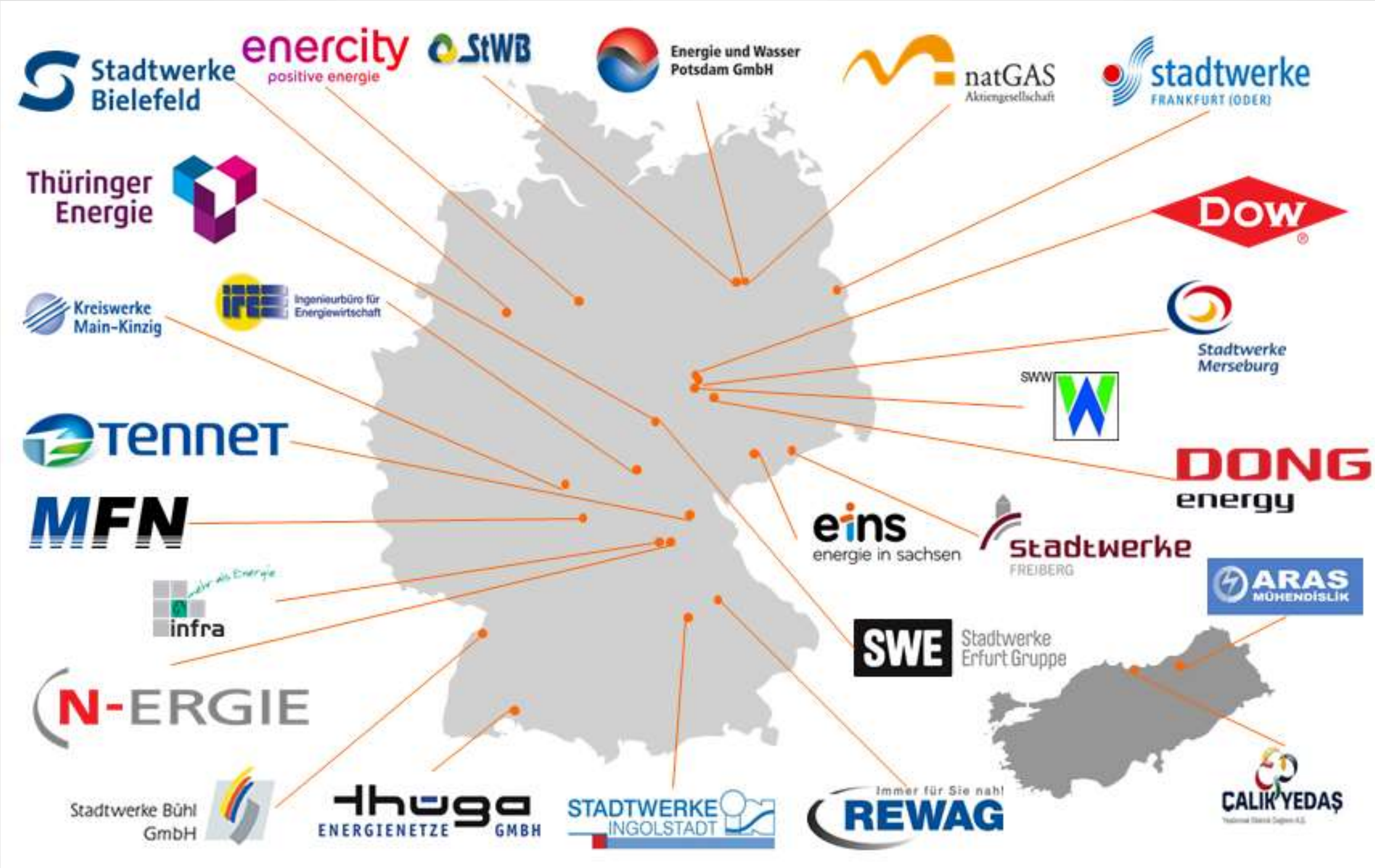
Fraunhofer
IOSB
Institutsteil Angewandte Systemtechnik AST

EMS-EDM PROPHET® – Modules 2015



© 2014 Fraunhofer IOSB-AST

EMS-EDM PROPHET® – Anwender



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EMS-EDM PROPHET® – Übersicht

- **ZRM** Zeitreihenmanagement
- **ZPS** Zeitreihenprognosesystem
- **RPS** Ressourcenplanungssystem
- **BKM** Bilanzkreismanagement
- **NNM** Netznutzungsmanagement
- **NMS** Netzmanagementsystem
- **SDL** Scheduler

Mathematical Optimization

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EMS-EDM PROPHET–RPS

- Optimierung
  - Kraftwerkseinsatz
  - Querverbund
  - Virtuelle Kraftwerke
  - Beschaffung
  - Handel
  - Regelenergie
  - Speicher
- Zahlreiche Modelltypen
  - LP, MIP, QMIP etc.
  - NLP, MINLP etc.
- Solver
  - CPLEX, GUROBI etc.
  - CONOPT, LINDO etc.

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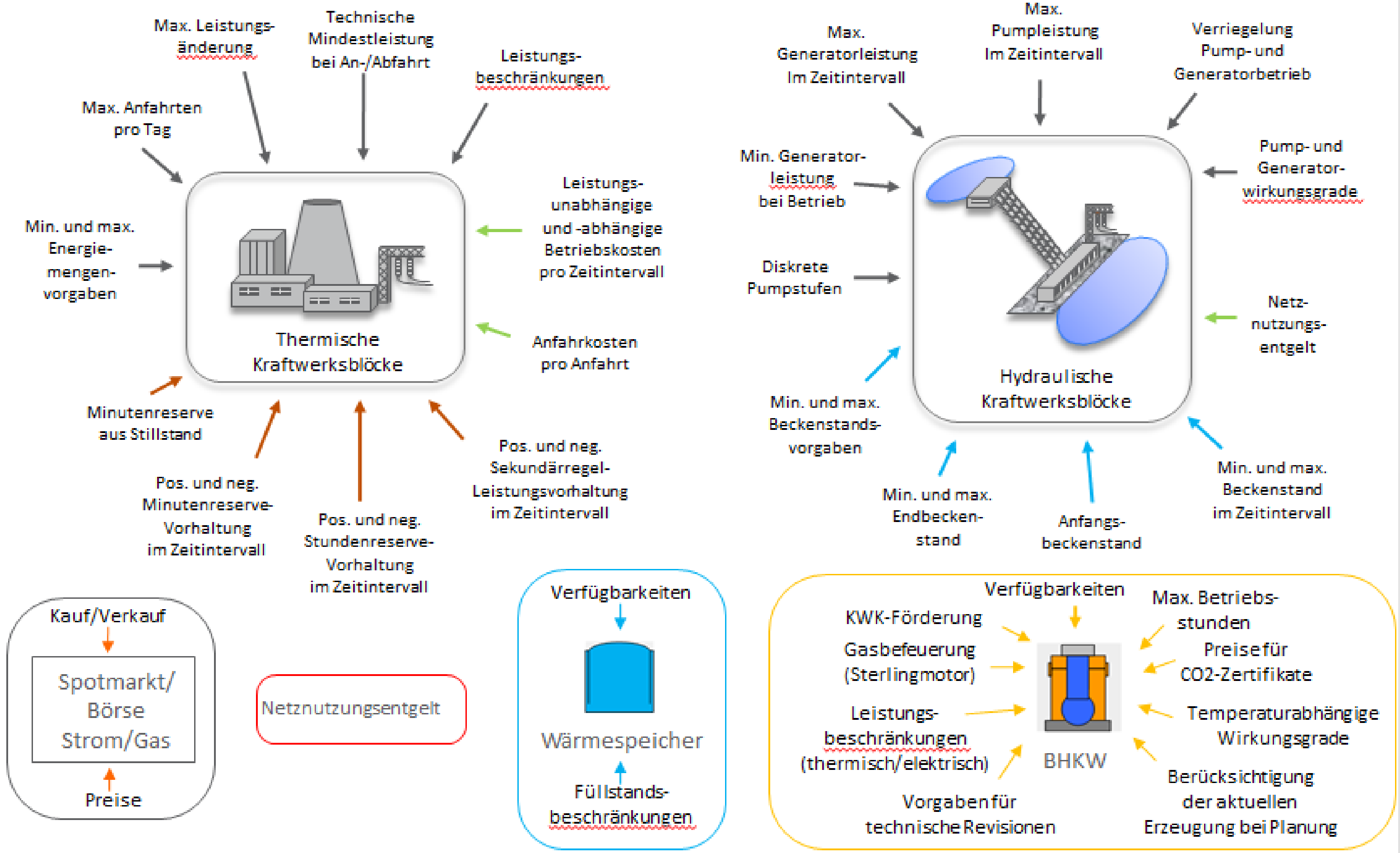
EMS-EDM PROPHET – RPS

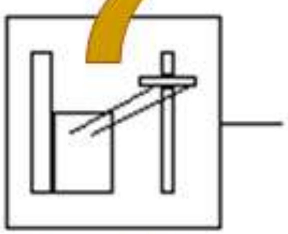
Modellkomponenten für skalierbare Systeme (Beispiele)



RPS – Modeling

Graphical modeling of optimization problems

Drag ´n Drop



Power plant

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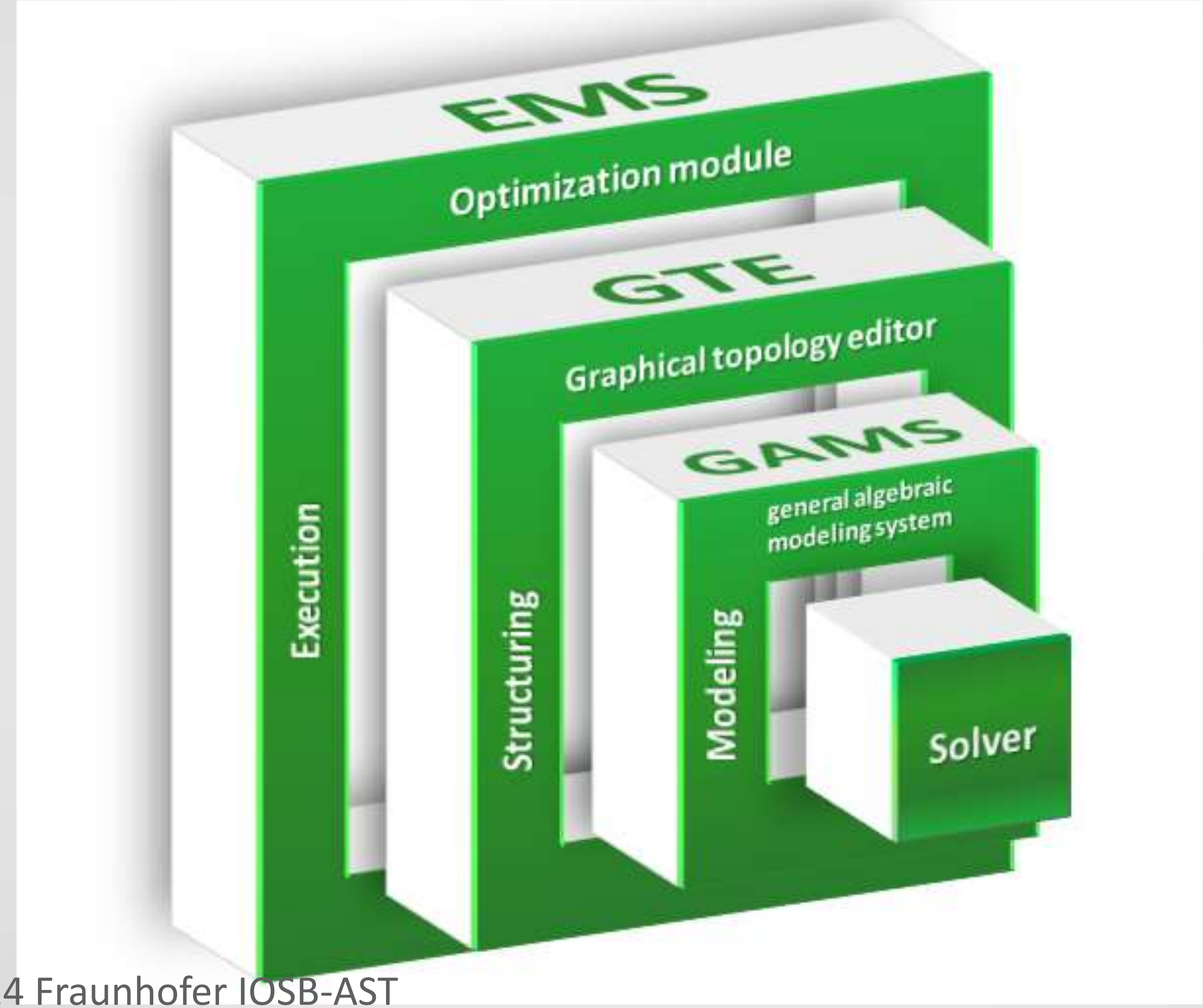
RPS - Modeling



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RPS – GAMS Log

Lade Optimierungs-DLL
Operation abgeschlossen 00:00
Lade Zeitbasis
Operation abgeschlossen: 00:00
Erzeuge Porjektverzeichnis und entferne temporäre Dateien
Operation abgeschlossen: 00:00
Erzeuge GAMS-Datei ...
schreibe Komponentendeklarationen
schreibe GDX-Daten
schreibe Instanzwerte
schreibe Set-Datenwerte
schreibe Set-Datenwerte für die Startbedingungen
schreibe Tabellen
schreibe Tabelle "Startzustandstabelle [NW_BK_034] "
...
Zeitbedarf GDX-Datei-Erzeugung [hh:mm:ss]: 00:00:09
schreibe Modelldaten
schreibe Instanzgleichungen
schreibe Bilanzgleichungen
schreibe Untermodellgleichungen
schreibe Objektfunktion
Schreiben der Deklarationsdatenwerte
Schreiben der Deklarationswerte abgeschlossen
Erzeuge Optionsdatei (OptFile)
Zeitbedarf GAMS-Datei-Erzeugung [hh:mm:ss]: 00:02:34
..
Durchführung der Optimierung ... [19.03.2014 01:00 - 23.03.2014 00:00]
Datei: "C:\GAMS\win64\24.3\gams.exe"
Parameter: "C:\EMS-EDM PROPHET\system\Rps-

EMS-EDM PROPHET–RPS

- Optimierung
  - Kraftwerkseinsatz
  - Querverbund
  - Virtuelle Kraftwerke
  - Beschaffung
  - Handel
  - Regelenergie
  - Speicher
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  - LP, MIP, QMIP etc.
  - NLP, MINLP etc.
- Solver
  - CPLEX, GUROBI etc.
  - CONOPT, LINDO etc.

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Fields of Fuel

A Multiplayer, Web-based Simulation Game

Wisconsin Institute for Discovery

Fields of Fuel (FoF) - Motivation

- **FoF** allow classes to explore the complex sustainability challenges associated with growing bioenergy crops.

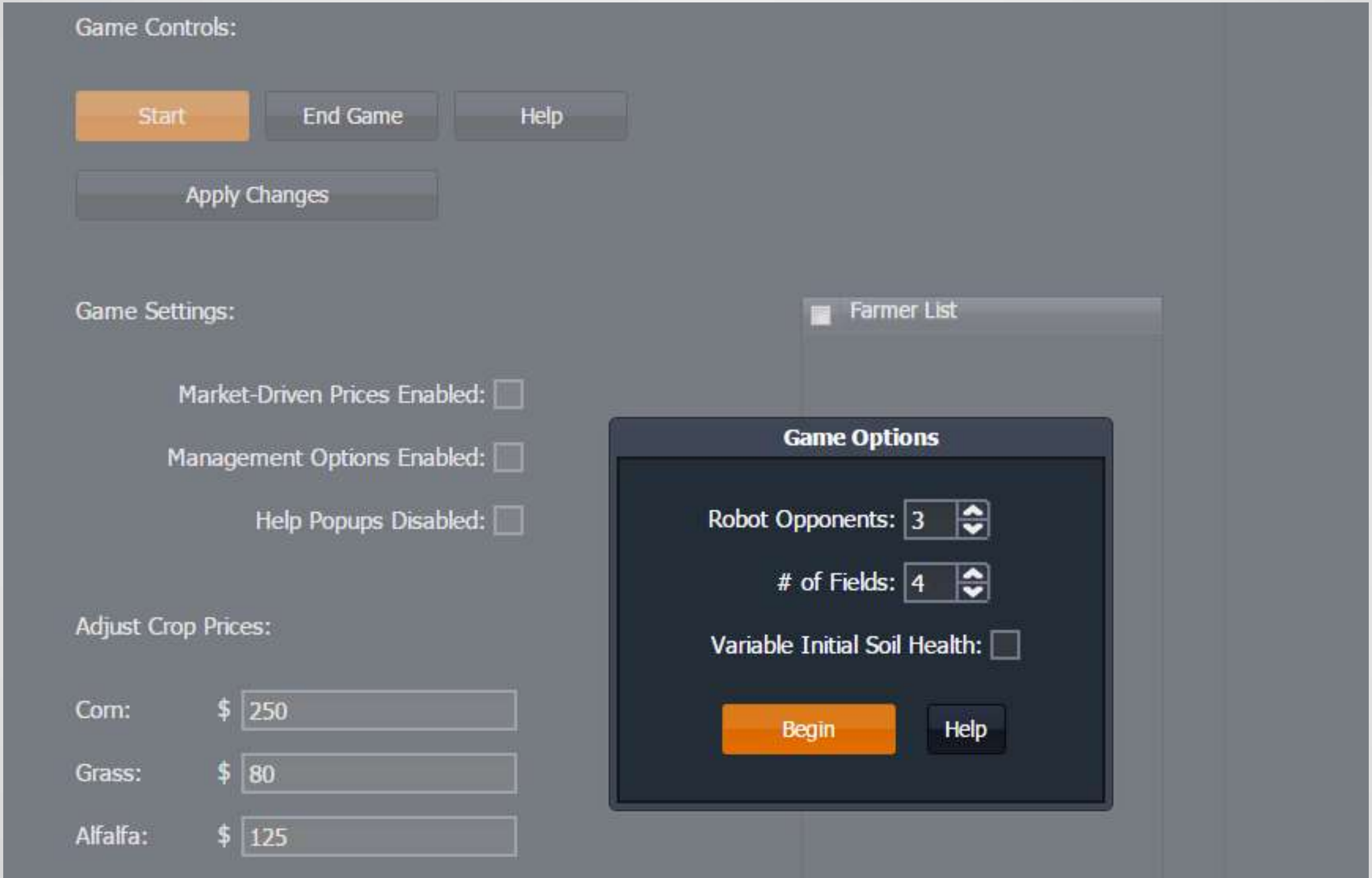
Sustainable Bioenergy Crop Production

SUSTAINABILITY CATEGORY	SCORE COMPONENT	SCORE SUBCOMPONENTS (DATA)
SOCIAL	ENERGY PRODUCTION	• CROP YIELD (MEGAGRAMS OF BIOMASS) • NET ENERGY (MEGAJOULES)
ECONOMIC	INCOME	• NET INCOME ($)
ENVIRONMENTAL	ENVIRONMENTAL QUALITY	• SOIL FERTILITY (SOIL CARBON) • WATER QUALITY (INDEX) • BENEFICIAL BUGS (INDEX) • GREENHOUSE GAS EMSSIONS (CO2 EQ.)

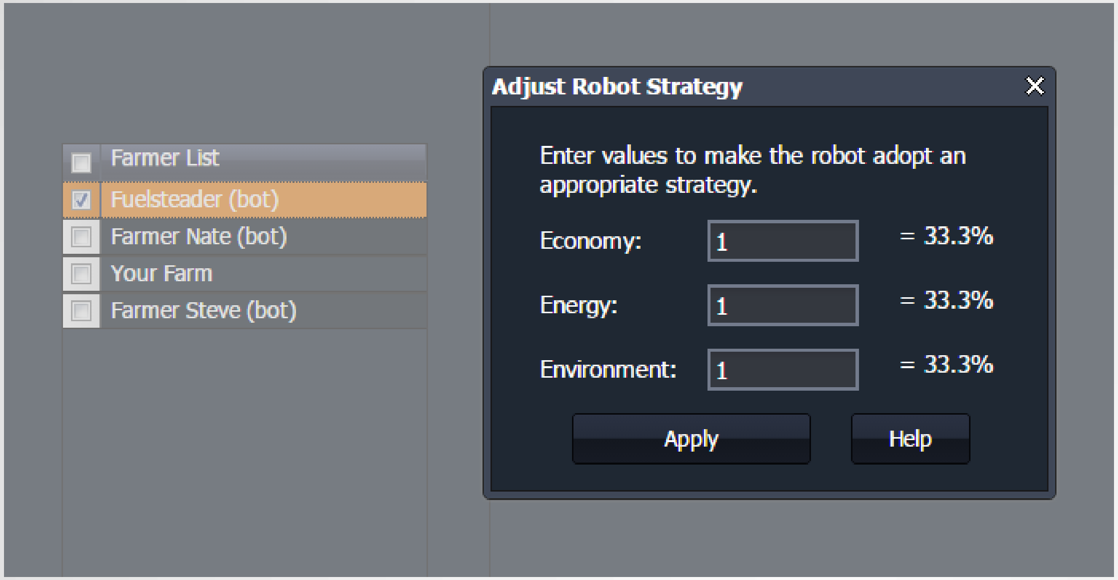
Sustainable Bioenergy Crop Production

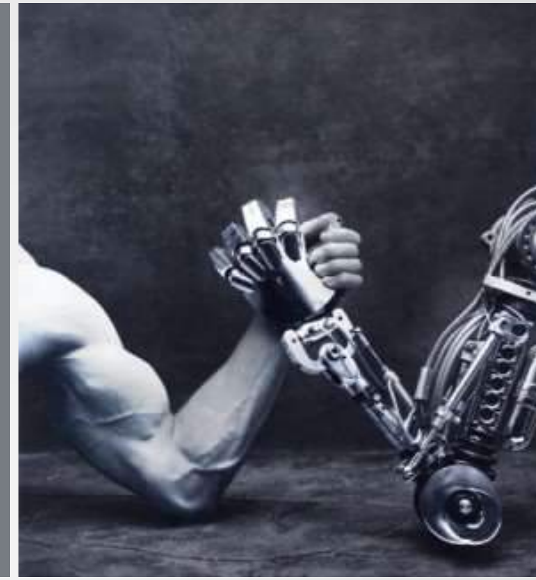
Crop Choices	Economics	Energy/Yield	Environment
Corn	High	High	Low
Alfalfa	Medium	Low (N/A)	High
Switchgrass	Low	Medium	High

Fields of Fuel – Setting up a Game



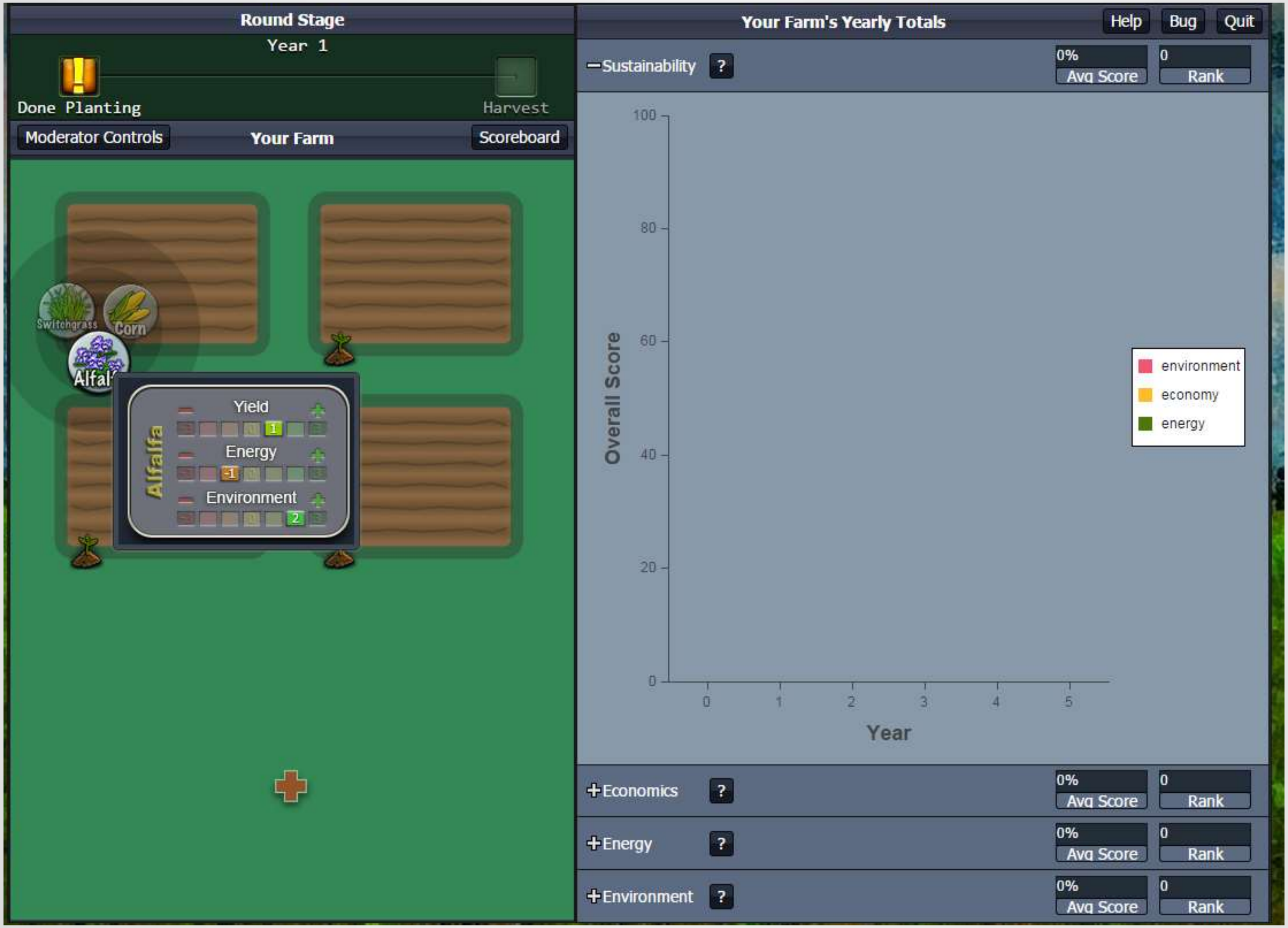
Fields of Fuel – GAMS robots





- Single player have the option of choosing the number of bots to play against; the player can also set the objective of each bot opponent.
- The robots optimize a weighted average of overall score and field health over a five year period.
- A mixed-integer nonlinear programming problem (MINLP) identifies the optimal future path to follow.

Fields of Fuel



Fields of Fuel

Fields of Fuel

GAMS

Fields of Fuel

fieldsoffuel.org

Wisconsin Institute for Discovery

Summary

AML – A Success Story

GAMS - Design Principles

- Simple, but powerful language for optimization problems
- Open interfaces
- Different layers

Examples

- Provide cutting edge technology
- Don't lock developers and users into a certain environment
- Protect investments of users
- Make mathematical optimization available to a broader audience

Bad Honnef,
November 2014

Thank You

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