## A tour of the GAMS ecosystem in 2023

Recent developments and some evergreens

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GAMS Software GmbH



Short introduction into GAMS

Tour of the GAMS ecosystem and its components

Studio

Transfer

Connect

MIRO

Engine

Summary



## Short introduction into GAMS

• Stands for: General Algebraic Modeling System



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- Conceived 1976 by World Bank, commercial since 1987



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- Conceived 1976 by World Bank, commercial since 1987
- Application areas wherever mathematical optimization is useful
- Many users from academic and commercial institutions
- Extensive software package with mathematical modeling language at its core



• Focused on declarative programming resembling mathematical notation



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- Central elements/keywords are: sets, parameters, variables, equations, and models



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- Focused on declarative programming resembling mathematical notation
- Central elements/keywords are: sets, parameters, variables, equations, and models
- Bridge between human and machine readable/executable model representation
- Imperative language constructs like branching and loops
- Flexibility, simplicity, and speed as key strengths of language and ecosystem with
  - 16 expressible model types: linear, quadratic, nonlinear, stochastic, ...
  - 37 solver links: SCIP, Gurobi, HiGHS, KNITRO, ...
  - 3 operating systems: Windows, Linux, macOS (x64 & ARM64)
  - Many data sources and sinks: CSV, GDX, HAR, pandas, Excel, Access, SQL, ...
  - 13 language bindings: C/C++, Python, MATLAB, R, Julia, .NET, Java, ...
  - Efficient model generation for sparse coefficient matrices (widespread "in the wild")
     → see "Performance in Optimization Models" at https://www.gams.com/blog



#### GAMS solver zoo and supported model types



### Knapsack problem definition and implementation

Backpack can hold weight c. Items  $i \in \mathcal{I}$  with utilities  $u_i$  and weights  $w_i$  are available to select.

$$x_i = \begin{cases} 1, & \text{iff. item } i \text{ is selected} \\ 0, & \text{otherwise.} \end{cases}$$

$$\max \sum_{i \in \mathcal{I}} u_i \cdot x_i$$

s.t.

$$\sum_{i \in \mathcal{I}} w_i \cdot x_i \le c$$
$$x_i \in \{0, 1\} \qquad i \in \mathcal{I}$$

set i "available items" / i1\*i4 /: scalar c "capacity of knapsack" / 8 / 5 parameters 6 u(i) "utility of item" / i1 10, i2 4, i3 5, i4 8 / w(i) "weight of item" / i1 8, i2 2, i3 4, i4 5 /; binary variable 9 x(i) "1 iff. item i is deposited into knapsack"; free variable utility "objective value of selection"; equations obj, cap; obj .. utility =e= sum(i, u(i)\*x(i)); 16 cap .. sum(i, w(i)\*x(i)) =l= c; model knapsack /all/; 19 solve knapsack using mip maximizing utility; display x.l;

Listing 1: knapsack.gms



# Tour of the GAMS ecosystem and its components

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Studio

• Integrated development environment for GAMS code



- Integrated development environment for GAMS code
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- Actively developed modern replacement of deprecated GAMS IDE
- Open source on GitHub: https://github.com/GAMS-dev/studio
- Runs natively on Windows, Linux, and macOS (x64 & ARM64)
- Relatively lightweight in terms of CPU and memory consumption
- Numerous features to help GAMS users
  - Handling of multiple file projects
  - Syntax highlighting, code completion, tooltips, help integration
  - Code folding, dark mode, and distraction free mode
  - · Interactive debugger with breakpoints and stepping
  - GDX (GAMS Data eXchange), listing file, and reference file viewers
  - Comfortable editor for GAMS configuration file
  - Integration of Engine, MIRO, and NEOS server



### User interface of GAMS Studio

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## Interactive debugging with GAMS Studio

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	* Assumption	otion is	topolo	gical	ordering of jobs, hence the last job is assigned the highest n	umber					
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133	* Forwar	d comput	ation	of ear	rliest finishing times (using precendece and durations)						
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38	lfts(j)	= card(T	);								
.39 68 <del>-</del>	for(iter	it, jt; pard(i) d	ownto	1							
41 -	Loop	(1\$(ord(	i)=it)	;							
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158	* If job	i is ac	tive i	n t it	t can finish in period tau						
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# Tour of the GAMS ecosystem and its components

Transfer

### **GAMS** Transfer

- An optimization model arises inside a machine learning or data science project?
- $\rightarrow$  API for data exchange with scripting language (Python, MATLAB, R)
- Container-oriented: Holds (linked) symbols with attributes and data (records)
- Symbol records have standardized format:
  - Python: Pandas DataFrame, numpy arrays
  - MATLAB: struct, table, dense matrix, sparse matrix
  - R: vector, data frame

• Batch read/writes through container (fast C++ backend under the hood)

```
import gamstransfer as gt
   import numpy as np
   m = gt.Container()
  items = [f'_i \{i+1\}]' for i in range(4)]
4
  us = np.array([10, 4, 5, 8])
  ws = np.array([8, 2, 4, 5])
6
   i = m.addSet('i', records=items, description='items')
   c = m.addParameter('c', records=8, description='capacity')
8
   u = m.addParameter('u', domain=i, records=us, description='utility')
9
   w = m.addParameter('w', domain=i, records=ws, description='weight')
   m.write('knapsack instance.adx')
                                                                                🖬 g a m s
```

Listing 2: knapsack\_transfer.gms

# Tour of the GAMS ecosystem and its components

Connect

• Processing data in arbitrary formats in a more descriptive way?



- Processing data in arbitrary formats in a more descriptive way?
- $\rightarrow\,$  Flexible system to read, transform and write data from various formats



- Processing data in arbitrary formats in a more descriptive way?
- $\rightarrow\,$  Flexible system to read, transform and write data from various formats
  - Available source/sink formats: CSV, SQL, Excel, and more to come...



- Processing data in arbitrary formats in a more descriptive way?
- $\rightarrow\,$  Flexible system to read, transform and write data from various formats
  - Available source/sink formats: CSV, SQL, Excel, and more to come...
  - Will replace most data exchange command line utilities (e.g. GDXXRW for Excel)





### Knapsack example with Connect

1	i,	u,	W
2	i1,	10,	8
3	i2,	4,	2
4	i3,	5,	4
5	i4,	8,	5

Listing 3: item\_data.csv

1	<pre>\$onEmbeddedCode Connect:</pre>
2	- CSVReader:
3	<pre>file: item_data.csv</pre>
4	name: u
5	indexColumns: 1
6	valueColumns: 2
7	- CSVReader:
8	<pre>file: item_data.csv</pre>
9	name: w
10	indexColumns: 1
11	valueColumns: 3
12	- GAMSWriter:
13	writeAll: True
14	<pre>\$offEmbeddedCode</pre>
15	<pre>parameter c /8/;</pre>

Listing 4: knapsack\_connect.gms

#### Harzer Wandernadel - excourse



• Over 200 stamp stations scattered across the Harz mountains in Germany



#### Harzer Wandernadel - excourse



- Over 200 stamp stations scattered across the Harz mountains in Germany
- Put stamp into your pass to "prove" visit during hike



#### Harzer Wandernadel - excourse



- Over 200 stamp stations scattered across the Harz mountains in Germany
- Put stamp into your pass to "prove" visit during hike
- More information available online:
  - https://www.harzer-wandernadel.de/
  - https://www.oberharzinfo.de/en/hiking-nature/harzer-wandernadel/ harzer-wandernadel-up-in-the-harz
#### Harzer Wandernadel - Excel input data set

.

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2			Dezimalgrade	Dezimalminuten	Grad-Min-Sek	UTM
1						
	1	Eckertalsperre (Staumauer)	N51.84165 E10.57998	N51° 50.499' E10° 34.799'	N51° 50' 29.9" E10° 34' 47.9	" 32 U 608845 5744605
	2	Scharfenstein (Rangerstation)	N51.83017 E10.60277	N51° 49.810' E10° 36.166'	N51° 49' 48.6" E10° 36' 10.0	" 32 U 610444 5743364
	3	Am Kruzifix	N51.84437 E10.61180	N51° 50.662' E10° 36.708'	N51° 50' 39.7" E10° 36' 42.5	" 32 U 611031 5744956
	4	Taubenklippe	N51.86213 E10.61860	N51° 51.728' E10° 37.116'	N51° 51' 43.7" E10° 37' 07.0	" 32 U 611456 5746943
	5	Froschtelsen	N51.85192 E10.65457	N51" 51.115' E10° 39.274'	N51" 51' 06.9" E10" 39' 16.4	" 32 U 613957 5745862
1	6	Bremer Hütte (Obere Ilsefälle)	N51.82868 E10.63485	N51° 49.721' E10° 38.091'	N51" 49' 43.3" E10' 38' 05.5	" 32 U 612658 5743249
1	7	Gasthaus Plessenburg	N51.83215 E10.66826	N51° 49.929' E10° 40.095'	N51" 49' 55.7" E10° 40' 05.7	" 32 U 614950 5743684
	8	Stempelsbuche	N51.81937 E10.62792	N51° 49.162' E10° 37.675'	N51" 49' 09.7" E10" 37' 40.5	" 32 U 612203 5742200
	9	Brockenhaus	N51.80054 E10.61578	N51° 48.032' E10° 36.947'	N51" 48' 01.9" E10" 36' 56.8	" 32 U 611413 5740087
	10	Große Zeterklippe	N51.80264 E10.64335	N51° 48.159' E10° 38.601'	N51" 48' 09.5" E10" 38' 36.1	" 32 U 613309 5740365
	11	Eckerloch	N51.78499 E10.61792	N51° 47.099' E10° 37.075'	N51" 47' 05.9" E10" 37' 04.5	" 32 U 611599 5738361
2	12	Achtermannshohe	N51.76145 E10.56913	N51' 45.687' E10' 34.148'	N51" 45" 41.2" E10" 34' 08.9	r: 32 U 608291 5735671
2	13	Anrensklint	N51.77356 E10.66719	N51' 46.414' E10' 40.031'	N51" 46" 24.8" E10" 40' 01.9	r 32 U 615027 5737168
	14	Schnarcherklippe (Schutzhütte)	N51.75445 E10.66565	N51" 45.267 E10" 39.939"	N51" 45" 16.0" E10" 39' 56.3	··· 32 U 614968 5735040
	10	Leistenkiippe	ND1.78102 E10.69378	ND1 40.091 E10 41.027	NO1 40 03.0" E10 41 37.6	32 0 010640 5738097
2	10	Ferdinandsstein Teodos etcla	ND1.82300 E10.65210	ND1 49.410 E10 39.126	NO1 49 24.0" E10' 39' 07.6	32 0 013660 5742698
1	1/	Frudenstein	ND1.77218 E10.69656	NO1 40.331'E10' 41.794'	NO1 40 19.9" E10. 41 47.6	32 0 01/056 5/3/063
	10	Grenzweg am Kaffeehorst	ND1.70183 E10.63245	NO1 45.110 E10 37.947	NO1 40 UD.0" E10" 37 56.8	32 U 012083 5734698
2	19	Paranhara (Nursiehtsnunkt)	ND1.82037 E10.57298	NO1 49.222 E10 34.3/9	NOT 49 13.3" E10' 34' 22.7	32 U 006414 5742229
1	20	Helenenruh Flend	NE1 7E407 E10 69001	NE1º 45.015 E10 40.505	NE1* 45 01.1 E10 40 30.2	32 0 013028 3734393
•	21	Gelber Briek	NE1 70102 E10.08091	NE1º 47 461' 510' 30 600'	NE1* 47 27 7* E10 40 51.2	32 0 010021 5735021
1	22	Mellenhouertern	NE1 90771 E10 65770	NE1º 49 462' 510' 30 469'	NE1* 49' 27.7 E10 38 41.3	22 0 013438 5739070
1	2.3	Welfeldane	NE1 91047 E10.65779	NE1º 40.402 E10 39.408	NE1*40'10 1* E10 39 28.1	20 014293 5740949
	24	Oberförster-Koch-Denkmal	N51 82528 E10 68840	N51° 49.100 E10 40.231	N51° 49' 31 0" E10° 41' 18 2	32 0 010350 5742953
1	25	Mönchshuche	N51 81783 E10 70789	N51° 49.017 E10 41.304	N51° 40' 04 2" E10° 42' 28 4	32 0 010330 3742953
ń	27	Ottofeken	N51 70660 E10 71105	N51° 47 801' E10° 42 717'	N51° 47' 48 1" E10° 42' 43 0	32 11 618053 5739812
~		ottorcach	······································	1034 471004 E10 42.717	NO1 47 4011 E10 42 4010	. 51 0 010033 3735012



Source: https://www.harzer-wandernadel.de/stempelstellen/gps-download/

#### Harzer Wandernadel - Specify table layout for Connect

```
$onEmbeddedCode Connect:
     - PandasExcelReader:
          file: HarzStampLocations.xlsx
          symbols:
              - name: stamplocations
                range: "Tabelle1!A3"
                type: set
                rowDimension: 6
                columnDimension: 0
     - Projection:
          name: stamplocations(nr,name,position1,position2,position3,position4)
          newName; i(nr)
          text: "{name}"
     - Projection:
          name: stamplocations(nr,name,position1,position2,position3,position4)
          newName: utmraw(nr)
          text: "{position4}"
     - PvthonCode:
19
          code: |
            # Split UTM of format "32 U eeeee nnnnn" into parameter utm
            utm records = []
            for r in connect.container["utmraw"].records.values:
               s = r[1], split()
               utm_records.append( (r[0], "east", float(s[-2])) )
               utm_records.append( (r[0], "north", float(s[-1])) )
            connect.container.addParameter("utm", domain=["*","*"], records=utm_records)
     - GAMSWriter:
28
          symbols:
29
             - name: i
             - name: utm
     $offEmbeddedCode
```

G A M S

#### Harzer Wandernadel - full optimal solution

- Local newspaper: Athlete visited all in 3 weeks
- Data fed into TSP model from GAMS Model Library
  - 2 minutes with CPLEX
  - 2.4 seconds with Concorde (coordinates as text)
- Optimal tour length: 557 km (Euclidean distance between nodes)
- $\rightarrow~\geq 26~{\rm km}$  per day for Athlete





#### Harzer Wandernadel - MIRO app and solution map



Try interactively: https://miro.gams.com/gallery/app\_direct/tsp/

Tour of the GAMS ecosystem and its components

MIRO

#### Configuration vs coding

- A few model annotations make GAMS model MIRO ready
- Widgets and graphs can be configured, but do not need to be programmed

#### Benefits

- Very quick results
- Extendable with custom R code













#### Knapsack example with MIRO

- Parameters (incl. scalars) are "external input"
- Variables are "external output"
- Remaining information related to MIRO are in its configuration (not model!)
- Detailed look (interesting application!) in Robin Schuchmann's talk (FA-16)

```
parameters
 $onExternalInput
  c capacity of knapsack / 8 /
3
  u(i<) utility of item / i1 10, i2 4, i3 5, i4 8 /
Δ
  w(i) weight of item / i1 8, i2 2, i3 4, i4 5/;
5
6 $offExternalInput
  $onExternalOutput
8 binary variable
9
  x(i) 1 iff. item i is put into knapsack;
  free variable
  utility objective value of selection;
  $offExternalOutput
```

Listing 6: knapsack\_miro.gms



## Knapsack input UI in MIRO

GeneralAlgebraicModeling	g S y s t e m				— (	
File Edit View Window Help						
S G A M S	≡				Scenario -	Help 👻
幸 Input	default					×
Output					1	144
GAMS interaction	Innuti	vidanto	utility of itom	weight of its		
E Load scenarios	input v	viugets	utility of Item	weight of iter		_
Compare scenarios				Search:		
			available items		utility of item	
Load data	1	i1			10.00	
	2	i2			4.00	
Solve model	3	13			5.00	
	4	14			8.00	

🖬 G A M S

#### Knapsack result visualization in MIRO



22/24

# Tour of the GAMS ecosystem and its components

Engine

• Running into local machine restrictions with runtimes and parallelism?





- Running into local machine restrictions with runtimes and parallelism?
- $\rightarrow\,$  Run and solve GAMS models as jobs in the cloud





- Running into local machine restrictions with runtimes and parallelism?
- $\rightarrow\,$  Run and solve GAMS models as jobs in the cloud
- Ideal for sensitivity analysis (what-if) and long-running jobs





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  - Tight integration with Studio and MIRO





- Running into local machine restrictions with runtimes and parallelism?
- $\rightarrow\,$  Run and solve GAMS models as jobs in the cloud
  - Ideal for sensitivity analysis (what-if) and long-running jobs
  - Tight integration with Studio and MIRO
  - More details in talk from Stefan Mann (TE-16)







What we covered: GAMS is more than just a modeling language

• Working in a modern integrated development environment with Studio



- Working in a modern integrated development environment with Studio
- $\bullet\,$  Data processing for MATLAB/Python/R data scientists with Transfer



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Further viewing and reading:

• Video-tutorials and -workshops on many topics/components on YouTube: https://www.youtube.com/user/GAMSLessons



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- Extensive documentation and reference: https://www.gams.com/latest/docs/
  - For MIRO: https://gams.com/miro/
  - For Engine: https://gams.com/engine/



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- Extensive documentation and reference: https://www.gams.com/latest/docs/
  - For MIRO: https://gams.com/miro/
  - For Engine: https://gams.com/engine/
- Open source projects (MIRO, Studio, Engine UI, C++-API, ...) on GitHub: https://github.com/orgs/GAMS-dev/repositories

## Thank you for your attention!



Leibniz University Hannover Germany



## **Backup slides**



## GAMS Studio configuration editor

	• \$P\$ ₩	· ·							
icome 🖸 🛛 kn	apsack.gms 🔝	gamsconfig.yaml* 🔀							
A . =			Filter	Parameters					343
<b>W I Z Y</b>								Desidentes	
Key	Value minVe	sion maxVersion	Para	Antian	Synonym	CE	(D. C. F. CT)	Type	CANC execution execution
GDX	dump			Action	~	CE.	(0, 0, 0,,01)	chumau	CompleOnly request
Action	CE			CF					Comple and Even te
IntVarUp	1			F					ExecuteOnly
Keen	-			GT					Trace Report
Neep	1			R					Restart After Solve
PUP	nioHS			AppendExpand	AE	1	{0,1}	EnumInt	Expand file append option
LP	GUROBI			AppendLog	AL	0	{0,1}	EnumInt	Log file append option
OptCR	0.0001			AppendOut	AD	0	{0,1}	EnumInt	Output file append option
OptCA	0			AsyncSolLst		0	{0,1}	EnumInt	Print solution listing when asynchronous solve (Grid or Threads) is used
ShowQSMemory	2			Bratio		0,25	[0, 1]	Double	Basis detection threshold
anono anemory	-			CaptureModelInstance		0	{0,1}	EnumInt	Switch to capture all model instances within a run
				Case		0	{0,1}	EnumInt	Output case option for LST file
				CErr		0	[0, 2147483647]	Integer	Compile time error limit
				CharSet		1	{0,1}	EnumInt	Character set flag
				CheckErrorLevel		0	{0,1}	EnumInt	Check errorLevel automatically after executing external program
				CNS				String	Constrained Nonlinear Systems - default solver
				Connectin				string	Specify YAML Connect script file processed at start of GAMS
				Connectuut	cm.			Soring	Specify TAML Connect script rile processed at end of GAMS
				Curbin	CDIF			String	Current arectory
				Decryptikey	00		(0.1.2)	Sung	Ney to decrypt a text rile that was efforypted via sencrypt
				Dist	M.		(W/4/6) (eff. en)	EnumEte	Cuiteb defends fen "Pen/offNeis"
				DNIR		011	four, out	Stripp	Non-Linear Programming with Directinuour Darivatives - default roker
				DocEla				String	Elenance stem for dog mentation files
				Domi im		0	[0 2147483647]	Integer	Domain violation limit solver default
				DumpOnt		0	{0.1.2.3.4.11.21}	EnumInt	Writes preprocessed input to the file input dmp
				DumpOptGDX			(constant) (tester)	Stripp	Defines a GDX file name stem created when using DumpOnt
				DumpParms	DP	0	(0.1.2)	EnumInt	GAMS parameter logging
				DumpParmsLooPrefix	DPLP	***	()	String	Prefix of lines triggered by DumpParms>1
				ECImplicitLoad		on	{off, on}	EnumStr	Allow implicit loading of symbols from embedded code or not
				EMP				String	Extended Mathematical Programs - default solver
				Empty		on	{off, on}	EnumStr	Switch default for "\$on/offEmpty"
				EncryptKey				String	Key to encrypt a text file using \$encrypt
				EolCom		off		String	Switch default for "\$on/offEolCom" and "\$eolCom"
				EpiOnly	EY			Immediate	Single key-value pairs (immediate switch)
				EpsToZero		off	{off, on}	EnumStr	Treat eps as zero when unloading to GDX
				ErrMsg		1	{0,1,2}	EnumEnt	Placing of compilation error messages
				ErrNam				String	Name of error message file
				Error				Immediate	Force a compilation error with message
				ErrorLog	ER	2147483643	( [0, 2147483647]	Integer	Max error message lines written to the log for each error
				ETUm	ETL	1e+299	[0, 1e+299]	Double	Elapsed time limit in seconds
				ExecMode		0	{0,1,2,3,4}	EnumInt	Limits on external programs that are allowed to be executed
				Expand	EF			String	Expanded (include) input file name
				FDDelta		1e-05	[1e-09, 1]	Double	Step size for finite differences
				FDOpt		0	{0,1,2,3,4,10,11,	EnumInt	Options for finite differences

C\Users\aschr\Documents\GAMS\gamsconfig.yaml

INS UTF-8

#### Extensive model library

lter mo	del tal	os									22
Model	Libraŋ	(429)	Test Library (898)	API Library (	61)	Data Utilities Library (146)	EMP Library (104)	FIN Library (42)	NOA Library (78)	PSO Libra	ry (31)
SeqNr	Lic	Name	Applicatio	on Area	Туре			Description			
64	D	ABEL	Macro Economi	cs	NLP	Linear Quadratic Control	Problem				
08	D	ABSMIP	Mathematics		MIP	Discontinous functions at	os() min() max() sign()	as MIPs			
88	D	AGRESTE	Agricultural Economics		LP	Agricultural Farm Level M	odel of NE Brazil				
08	D	AIRCRAFT	Management So	ience and OR	LP	Aircraft Allocation Under	Uncertain Demand				
89	с	AIRSP	Stochastic Progr	amming	LP	Aircraft Allocation					
96	с	AIRSP2	Stochastic Progr	amming	DECIS	Aircraft Allocation - stoch	astic optimization wit	th DECIS			
60	D	AJAX	Management So	tience and OR	LP	Ajax Paper Company Proc	duction Schedule				
24	D	ALAN	Finance		MIN	A Quadratic Programming	g Model for Portfolio	Analysis			
65	D	ALKYL	Chemical Engine	ering	NLP	Simplified Alkylation Proc	ess				
96	D	ALLBASES	Micro Economic	s	MIP	Enumerate all Feasible Ba	sic Solutions of the Ti	ansportation Proble	m		
70	D	ALPHAM.	. Recreational Mo	dels	MIP	Alphametics - a Mathema	tical Puzzle				
31	с	ALUM	International Tra	ide	MIP	World Aluminum Model					
74	D	AMPL	Management So	ience and OR	LP	AMPL Sample Problem					
44	L	ANDEAN	Micro Economic	s	MIP	Andean Fertilizer Model					
97	D	APL1P	Stochastic Progr	amming	DECIS	Stochastic Programming	Example for DECIS				
98	D	APL1PCA	Stochastic Progr	amming	DECIS	Stochastic Programming	Example for DECIS				
30	D	ASYNCI	GAMS Language	e Features	MIP	Asynchronous processing	of incumbents repor	ted by GAMS/CPLE	<		
03	L	ASYNCJ	GAMS Language	e Features	GAMS	Execute asynchronously s	everal GAMS jobs and	d collect the fastest			
11	D	ASYNCL	GAMS Language	e Features	LP	Transportation Problem w	ith async loop body	execution			
96	D	AWKQAP	GAMS Tools		MIQ	Input file generation with	AWK for the Quadrat	tic Assignment Prob	lem		
98	D	AWKTSP	GAMS Tools		MIP	Traveling Salesman Proble	em Instance prepared	with AWK			
90	D	BADMIP	Management Sc	ience and OR	MIP	Rounding Problems in MI	Ps				
19	D	BATCHDES	Chemical Engine	ering	MIN	Optimal Design for Chem	ical Batch Processing				
87	L	BCHFCNE	T Branch and Cut	and Heuristic	MIP	Fixed Cost Network Flow	Problem with Cuts us	ing BCH Facility			
89	D	BCHMK	Branch and Cut	and Heuristic	MIP	Multi knapsack problem u	using BCH Facility				
88	D	BCHOIL	Branch and Cut	and Heuristic	MIP	Oil Pipeline Design Proble	em using BCH Facility				
49	D	BCHSTO	Branch and Cut	and Heuristic	MIP	Cutting Stock - A Column	Generation Approac	h with BCH			
86	D	BCHTLBAS	Branch and Cut	and Heuristic	MIN	Trim Loss Minimization w	ith Heuristic using BC	H Facility			
48	D	BCHTSP	Branch and Cut	and Heuristic	MIP	Traveling Salesman Proble	em Instance with BCH				

```
ws = GamsWorkspace()
1
2 db = ws.add_database()
   items = [f'i{i + 1}' \text{ for } i \text{ in range}(4)]
  utilities, weights = [10, 4, 5, 8], [8, 2, 4, 5]
4
   i = db.add_set('i', 1, 'available items')
5
6 for item in items: i.add_record(item)
7 c = db.add_parameter('c', 0, 'capacity of knapsack')
  c.add record().value = 8
8
   u = db.add_parameter('u', 1, 'utility of item')
9
   for item, utility in zip(items, utilities):
       u.add_record(item).value = utility
   w = db.add_parameter('w', 1, 'weight of item')
   for item, weight in zip(items, weights):
       w.add_record(item).value = weight
14
   db.export('knapsack_instance.qdx')
16
  . . .
```

Listing 7: knapsack\_pyapi.gms



#### **GAMS Engine architecture internals**



#### **GAMS Engine architecture internals**



#### GANTT chart for a RCPSP instance in MIRO

- Convert time periods  $1 \dots T$  to dates for interoperability with 'timevis'
- Model available via 'gamslib rcpsp' from GAMS model library

```
set ds /2020-01-01/:
2 $onMulti
3 $onEmbeddedCode Python:
  from datetime import date
4
  def to_date(t):
5
      refdate = date.toordinal(date(2020, 1, 1))
6
      return date.fromordinal(refdate + t).strftime("%Y-%m-%d")
  ds=[to_date(int(t.replace('t', ''))) for t in gams.get('t')]
8
  gams.set("ds", ds)
9
  $offEmbeddedCode ds
0
  alias(ds, start, end);
1
  $onExternalOutput
  parameter gantt(j, start, end, r);
  $offExternalOutput
4
  gantt(j, start, end, r)$(st(j)=ord(start) and st(j)+durations(j)=
15
      ord(end) and demands(j,r) > 0) = demands(j,r);
```

Listing 8: rcpsp\_miro.gms


### Resulting schedule for the RCPSP in MIRO







Modellers/Developers



🔷 G A M S Engine -Deployment Solution Solves GAMS models on centralized resources (on-prem or cloud) REST API . (user & job management) GAMS job scheduling & . Load balancing \land g a m Job Queue 📖 BROKER (REST APD **IT Admins** Transparent to End Users  $\rightarrow$ 









• Similar to Wandernadel but some tags intentionally difficult to find





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- Prove visit by putting secret code into smartphone app with online highscore





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  - 1. Fetch locations as JSON via REST-API (Embedded Code)





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  - 2. Fill location set and UTM coordinates into GAMS symbols (Embedded Code)





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  - 3. Solve TSP model with CPLEX

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  - 4. Write solution to CSV (Connect)





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  - 2. Fill location set and UTM coordinates into GAMS symbols (Embedded Code)
  - 3. Solve TSP model with CPLEX
  - 4. Write solution to CSV (Connect)
  - 5. Convert into GPX file (Python script)







• GAMS/CPLEX needs 4min 20s and Concorde/CPLEX just 1.7s







- GAMS/CPLEX needs 4min 20s and Concorde/CPLEX just 1.7s
- Optimal tour for all 419 tags is  $\geq 371$  km (as the crow flies)







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- GAMS/CPLEX needs 4min 20s and Concorde/CPLEX just 1.7s
- Optimal tour for all 419 tags is  $\geq 371$  km (as the crow flies)
- Many tag locations too far off paths
- Komoot routing struggles to cover first 80 waypoints with a hiking route
- Shows limitations of using euclidean distances (vs. walkable connections)



• GAMS is well-suited for model definition but not algorithmic programming



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- $\rightarrow\,$  Solution: Use API to interact with GAMS from Python



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Control and data API

• Object-oriented: Database, symbols (sets, parameters, variables), and records



- GAMS is well-suited for model definition but not algorithmic programming
- $\rightarrow\,$  Solution: Use API to interact with GAMS from Python

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- Create and read GAMS Data eXchange (GDX) files



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- Re-solve slightly modified instances without full model re-generation
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- Similar APIs also available for: .NET, Java, MATLAB, C++



- GAMS is well-suited for model definition but not algorithmic programming
- $\rightarrow\,$  Solution: Use API to interact with GAMS from Python

- Object-oriented: Database, symbols (sets, parameters, variables), and records
- Create and read GAMS Data eXchange (GDX) files
- Trigger GAMS jobs with custom options from code
- Re-solve slightly modified instances without full model re-generation
- Retrieve result data back to native data structures
- Similar APIs also available for: .NET, Java, MATLAB, C++
- More details in Justine's talk coming up next in this session



#### Python API: solve with varying knapsack capacities

```
job = ws.add_job_from_file('knapsack_mi.gms')
2
  cp = ws.add_checkpoint()
   job.run(checkpoint=cp)
4
   mi = cp.add modelinstance()
5
6
   mi capacity = mi.svnc db.add parameter("c", 0, "varying capacity")
   mi.instantiate('knapsack use mip max utility', GamsModifier(mi_capacity))
   mi capacity.add record().value = 1
8
   for cap_vary in range(6, 12):
9
       mi_capacity.first_record().value = cap_vary
       mi_solve()
       print(f'Maximum utility for capacity {cap_vary}: {mi.sync_db["
             utility"].find_record().level}')
```

Listing 9: knapsack\_pyapi.gms

```
        1
        Maximum utility for capacity 6: 9.0

        2
        Maximum utility for capacity 7: 12.0

        3
        Maximum utility for capacity 8: 12.0

        4
        Maximum utility for capacity 9: 13.0

        5
        Maximum utility for capacity 10: 14.0

        6
        Maximum utility for capacity 11: 17.0
```

Listing 10: output



#### Embedded code

• Only fragments of Python code required to "decorate" GAMS model?

 $\rightarrow$  Intersperse snippets inside a GAMS model with easy API for data exchange

```
$include knapsack_core
    $onEmbeddedCode Pvthon:
    import urllib.request
    import zipfile
 4
    def ints(coll): return [ int(elem) for elem in coll ]
 5
    url='http://artemisa.unicauca.edu.co/~johnyortega/instances_01_KP/
 6
          instances_01_KP.zip'
    urllib.request.urlretrieve(url, 'instances.zip')
    with zipfile.ZipFile('instances.zip', 'r') as zip_ref:
 8
        zip_ref.extractall('instances')
9
    with open('instances/low-dimensional/f1 l-d kp 10 269') as fp:
        lines = fp.readlines()
    num_items, capacity = ints(lines[0].split())
    items = [f'ifi+1]' for i in range(num items)]
    utilities = ints([ line.split()[0] for line in lines[1:] ])
14
    weights = ints([ line.split() [1] for line in lines[1:] ])
    gams.set('i', items)
16
    gams.set('c', [capacitv])
    gams.set('u', list(zip(items, utilities)))
18
    gams.set('w', list(zip(items, weights)))
19
    $offEmbeddedCode i c u w
    model knapsack /all/:
    solve knapsack using mip maximizing utility;
```

