

Cyberinfrastructure and Optimization

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Topics

Concepts

- ❖ Infrastructure & cyberinfrastructure
- ❖ Software as a service

Optimization services

- ❖ COIN-OR open-source software
- ❖ The NEOS Server
- ❖ The OS project
- ❖ Intelligent optimization systems

Cyberinfrastructure for optimization

- ❖ Advanced computing resources
- ❖ Cloud computing

What is an infrastructure?

Familiar examples

- ❖ Transportation: road, rail, air
- ❖ Energy: power grids, pipelines
- ❖ Communications: mail, packages, phone

Common characteristics

- ❖ Doesn't *do* things; rather, *makes things possible*
- ❖ Facilitates activities *not initially foreseen*
- ❖ Relies on *standards*
- ❖ Requires broad *accessibility*

What is a cyberinfrastructure?

Infrastructure for computing

- ❖ Internet
- ❖ Web
- ❖ Supercomputer centers

Infrastructure for computing in some field

- ❖ Nanotechnology
- ❖ Seismology
- ❖ Optimization . . .

What is cyberinfrastructure research?

Ask the (U.S.) NSF . . .

- ❖ National Science Foundation
Blue-Ribbon Advisory Panel on Cyberinfrastructure
- ❖ *Revolutionizing Science and Engineering
Through Cyberinfrastructure*
 - * www.nsf.gov/od/oci/reports/toc.jsp

Organization

- ❖ Office of Cyberinfrastructure
- ❖ Independent of programs in traditional areas

Workshops

- ❖ Over 30 reports
 - * www.nsf.gov/od/oci/reports.jsp
- ❖ *An Operations Cyberinfrastructure:
Using Cyberinfrastructure and Operations Research
to Improve Productivity in American Enterprises*
 - * <http://www.optimization-online.org/OCI/OCI.pdf>

Implications for Optimization Research

CI Focus at government agencies

- ❖ Big science
- ❖ Custom-built, specialized software
- ❖ Focused application

CI Focus in the optimization community

- ❖ Small science
- ❖ General-purpose software
- ❖ Broad distribution

Special circumstances of optimization

- ❖ Independence of modeling software, solver software, data
- ❖ Sensitivity of solver choice to mathematics of problem
- ❖ Huge variation in solver performance

Software as a Service (“SaaS”)

as a Product

- ❖ You install & run on local computers
- ❖ You maintain & upgrade

as a Service

- ❖ They install on their servers
- ❖ You run on their servers
- ❖ They maintain & upgrade

Software as a Service (examples)

Tax preparation

The screenshot shows the TurboTax Free Edition 2008 web interface in a Windows Internet Explorer browser. The browser's address bar displays the URL: <https://qtwu1.turbotaxonline.intuit.com/secure/ttonline.htm?uid=145594932%3A0&csrc=4547200000&prodic>. The browser's search bar contains the text "Google". The browser's menu bar includes "File", "Edit", "View", "Favorites", "Tools", and "Help". The browser's toolbar includes "Google", "turbotax online", "Search", "Find", "AutoFill", and "4er". The browser's status bar shows "TurboTax Free Edition 2008".

The TurboTax interface features a navigation menu with "Home", "Personal Info", "Federal Taxes", "Federal Review", "State Taxes", "Print & File", and "Tools". The "Federal Taxes" section is active, showing a "Federal Refund" of "\$0".

The main content area is titled "You & Your Family" and "Tell Us About 2008:". It contains several sections with radio button options:

- Marital Status** (On Dec 31, 2008):
 - I was single
 - I was married
 - I was in another legally recognized relationship
 - I was divorced
 - I was legally separated
 - I was widowed
- Family**:
 - I had children or other dependents
 - I had no children or other dependents
 - I adopted a child
 - I financially supported a relative
- Home**:
 - I owned my home
 - I paid rent
 - I sold my home
 - I refinanced my home
- Job**:
 - I had one job
 - I had more than one job
 - I lost a job
 - My home and job were in different states

On the right side of the interface, there is a "Live Community" section with a search bar, a "Leaderboard", and a list of "View Popular Answers" including questions like "Does the Stimulus that we got last year get deducted from..." and "can i file for 2007?". There is also an "Answer a Question" section.

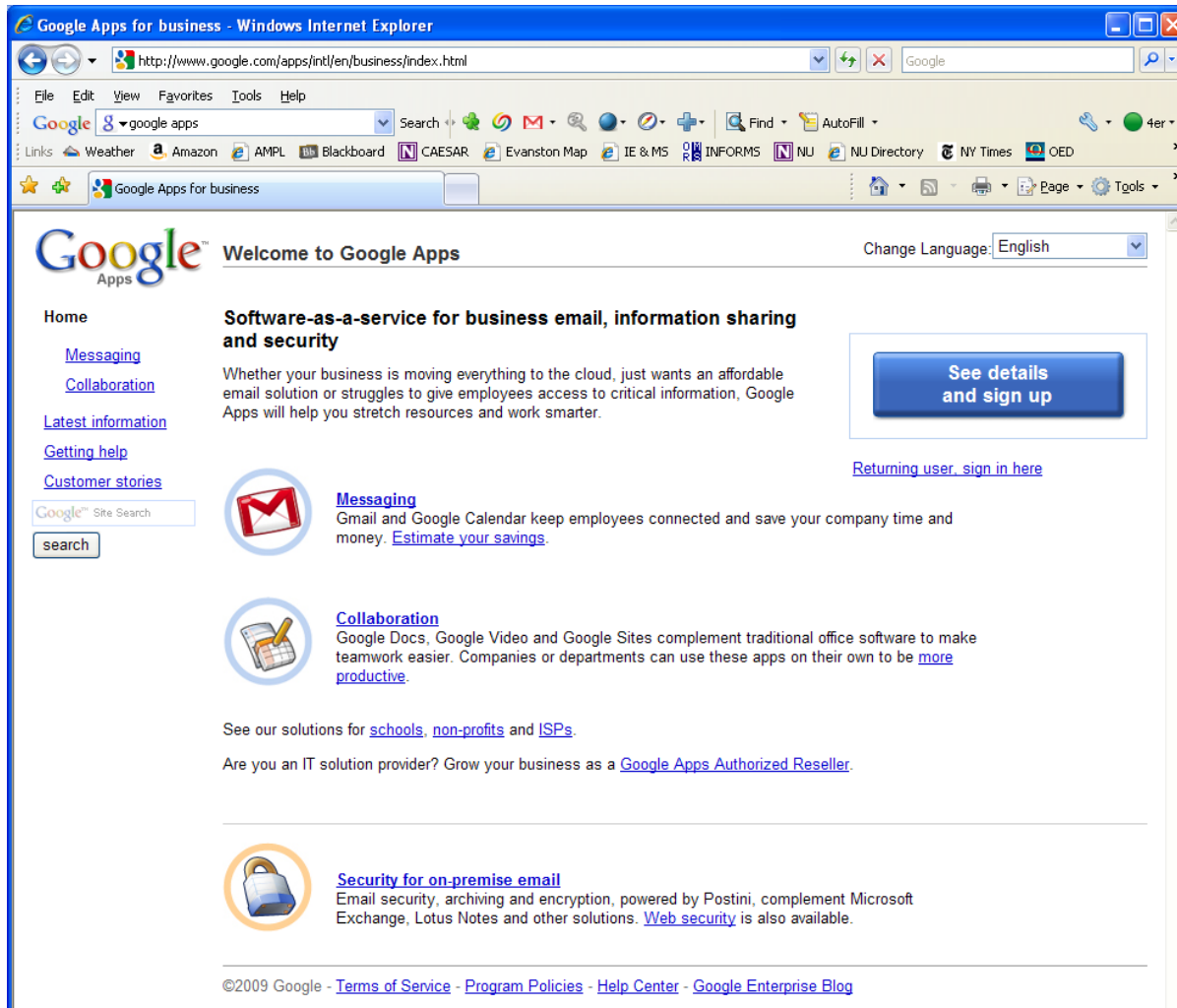
Software as a Service (examples)

Customer-relationship management

The screenshot shows the Salesforce.com website in a Windows Internet Explorer browser. The page features the Salesforce logo with the tagline "Success. Not Software." and navigation links for "Customer Login", "FREE TRIAL", and "1-800-NO-SOFTWARE". A search bar is present. The main content area includes a large blue banner with a quote: "Why would you ever buy and install software ever again?" attributed to Mark Silber, IT Systems Architect at Qualcomm. To the right of the banner are buttons for "free trial" (Salesforce CRM for 30 days) and "view demo", along with a vertical list of links: "learn", "try", and "buy". Below the banner are two boxes: "Salesforce CRM" (manage & share customer information) and "Force.com Platform" (dream & build any application). At the bottom, a section titled "The leader in customer relationship management (CRM) & cloud computing" displays logos for Corporate Express, QUALCOMM, Starbucks, SIEMENS, PERMANENTE, 郵便局 (JP Post Office), and ciena.

Software as a Service (*examples*)

Communication



The screenshot shows a Windows Internet Explorer browser window displaying the Google Apps for business homepage. The address bar shows the URL <http://www.google.com/apps/int/en/business/index.html>. The page features the Google Apps logo and a navigation menu with links for Messaging, Collaboration, Latest information, Getting help, and Customer stories. A search bar is also present. The main content area is titled "Welcome to Google Apps" and includes a "Change Language" dropdown set to "English". The primary message is "Software-as-a-service for business email, information sharing and security", accompanied by a "See details and sign up" button. Below this, there are three featured sections: "Messaging" (highlighting Gmail and Google Calendar), "Collaboration" (highlighting Google Docs, Video, and Sites), and "Security for on-premise email" (highlighting email security and encryption). The footer contains copyright information for 2009 Google and links to Terms of Service, Program Policies, Help Center, and Google Enterprise Blog.

Software as a Service (examples)

Office

The screenshot shows a Windows Internet Explorer browser window displaying the Microsoft Office web interface. The address bar shows the URL <http://cid-a1fdb07dfd9a22af.office.live.com/>. The page header includes navigation links for Windows Live, Hotmail (1), Messenger, Office, Photos, and MSN, along with the user profile [bob@4er.org](#) and options for profile and sign out.

The main content area is titled "Office" and indicates "Someone on Windows Live" is using Office. It features a "Personal" sidebar with a list of folders: AMPL, INFORMS Impact 2010, My Documents, Northwestern, Personal, Talks, and a "View all" link. Below this is a "Shared with me" section with a "View all" link and a "connect simply Go" logo.

The central area displays "Recent documents on SkyDrive" with a search bar and a "bing" logo. The documents listed are:

Document Name	Owner	Last Modified
OR2010 Munich CI Sem...	Someone on W...	3 days ago
STATUS OR	Someone on W...	5 days ago
Susman	Someone on W...	Aug. 24
AMPL_Trial_Use	Someone on W...	Aug. 14
AMPL Flier	Someone on W...	Aug. 14

Below the document list are links for "View all" and "SkyDrive", and a "Messenger social" section with the text "Your friends haven't done anything new with documents lately. Add people".

On the right side, there is a section titled "Create a new online document" with icons for Word, Excel, PowerPoint, and OneNote. Below this is a promotional banner for "Go Back To School" grant funding, which includes the text: "AUG 2010- You may qualify for a financial aid package which can help you return to school. Grants and scholarships can also help you pay for your degree." and a "Select Your Age:" dropdown menu.

Implications for Optimization

Menu of products

- ❖ Solvers
- ❖ Modeling systems

... independent and interchangeable

Potential impact

- ❖ Making products more readily available
- ❖ Facilitating comparison of products
- ❖ *Providing access to advanced computing resources?*

Progress in Optimization Services

COIN-OR open-source software

The NEOS Server

The OS Project

Intelligent optimization systems

Computational Infrastructure for Operations Research

- ❖ Repository for open-source software for optimization
- ❖ Operated by nonprofit COIN-OR Foundation
 - * Origins at IBM (2000)
 - * Currently hosted by INFORMS
- ❖ Mission:
 - * Develop, manage & distribute
 - * OR software, models, and data so that
 - * OR professionals can benefit from
 - * peer-reviewed, archived, openly-disseminated software
- ❖ Strongest in optimization

Relevance to cyberinfrastructure

- ❖ Tools are open for any use
- ❖ Each tool has many potential applications
- ❖ Presentation, access, maintenance are standardized

Open-Source Software

Things to know

- ❖ Free, but subject to licensing restrictions
- ❖ Licenses vary considerably
- ❖ Equally available to all user classes
- ❖ Possibly owned (in part) by
 - * Co-authors
 - * Employer
 - * Granting Agencies
 - * Owner of the machines it was written on

Examples

- ❖ GNU Public License, GNU Library Public License
- ❖ Eclipse Public License / Common Public License
- ❖ Mozilla Public License
- ❖ Apache License
- ❖ BSD Licenses

Open-Source Software at COIN-OR

Solvers

- ❖ Linear continuous & discrete
- ❖ Nonlinear continuous & discrete
- ❖ Semidefinite
- ❖ Stochastic

. . . source & binary

Infrastructures

- ❖ Developer tools
- ❖ Optimization utilities
- ❖ Interfaces
- ❖ Modeling systems and environments

. . . more later on Optimization Services

Getting Published on COIN-OR

Scope

- ❖ Useful to Operations Research professionals
- ❖ Not clearly better suited to another repository

Requirements

- ❖ Working Code
- ❖ Documentation
- ❖ Legal

Operational Policies

COIN-OR Requirements

Working code

- ❖ The project has some type of “tests”
- ❖ The tests are in a form that can be easily supplemented
- ❖ No other specific requirements on form or magnitude
 - . . . tests ensure the code remains working as it evolves*

COIN-OR Requirements (*cont'd*)

Documentation

- ❖ Authors
- ❖ Install
 - * How to build, install, and run on at least one platform
 - * Any platform, any computing language
- ❖ Readme (FAQs)
 - * What is the project name?
 - * What is the project for?
 - * Who is the maintainer?
 - * How do I contact the maintainer?
 - * How do I run the project once it's built or installed?
 - * How do I report a bug?
- ❖ Copying
 - * Licensing information

COIN-OR Requirements (*cont'd*)

Legal (new format)

- ❖ License
 - * Any certified open-source license (see www.opensource.org)
 - * Common/Eclipse Public License recommended (*IBM origins*)
- ❖ Required paperwork
 - * *List of authors*
 - * *Committers' Statements of Respect for Ownership*
 - * *Contributors' Statement of Ownership and Licensing*
- ❖ Recommended paperwork
 - * *Owner's Confirmation of Licensing*
 - * *Contributors' Statements of Respect for Ownership*
- ❖ Optional paperwork
 - * *List of authors & their contributions*
 - * *Committers' permissions from employers*
 - * *Detailed contributor & contribution logs*

NEOS neos.mcs.anl.gov

Network Enabled Optimization System

- ❖ Server
 - * free Internet access to over 60 solvers
- ❖ Guide
 - * tutorials, case studies, test problems, FAQs

Relevance to cyberinfrastructure

- ❖ Facilitates many uses
 - * but does not anticipate particular applications
- ❖ Makes all solvers open to anyone
- ❖ Supports standard problem representations
- ❖ Uses Web standards & protocols
 - * XML files
 - * callable via XML-RPC

NEOS Server

A general-purpose optimization server

- ❖ Over 45 solvers in all
 - * Linear, linear network, linear integer
 - * Nonlinear, nonlinear integer, nondifferentiable & global
 - * Stochastic, semidefinite, semi-infinite, complementarity
- ❖ Commercial as well as experimental solvers
- ❖ Central scheduler with distributed solver sites
- ❖ 20,000 submissions in a typical month

... has handled over 100,000

A research project

- ❖ Currently free of charge
- ❖ Supported at Argonne National Laboratory since 1996
- ❖ *Planned move* to Wisconsin Institutes of Discovery in late 2010

Design

Flexible architecture

- ❖ Central controller and scheduler machine
- ❖ Distributed solver sites

Standard formats

- ❖ Low-level formats: MPS, SIF, SDPA
- ❖ Programming languages: C/ADOL-C, Fortran/ADIFOR
- ❖ High-level modeling languages: AMPL, GAMS

Varied submission options

- ❖ E-mail
- ❖ Web form
- ❖ Direct call via XML-RPC
 - * from AMPL or GAMS client
 - * from user's client program using NEOS's API

... server processes submissions of new solvers, too

Range of Solvers

For familiar problem types

- ❖ Linear programming
- ❖ Linear network optimization
- ❖ Linear integer programming
- ❖ Nonlinear programming
- ❖ Stochastic linear programming
- ❖ Complementarity problems

For emerging problem types

- ❖ Nondifferentiable optimization
- ❖ Semi-infinite optimization
- ❖ Global optimization
- ❖ Nonlinear integer programming
- ❖ Semidefinite & 2nd-order cone programming

... virtually every published semidefinite programming code

Contributors

Open-source solvers

- ❖ GLPK, CBC, Bonmin (mixed integer)

Research solvers

- ❖ BonsaiG (mixed integer)
- ❖ FILTER, LANCELOT, LOQO, MINOS, SNOPT (nonlinear)

Commercial solvers

- ❖ Xpress, FortMP (mixed integer)
- ❖ CONOPT, KNITRO, MOSEK (nonlinear)

Commercial modeling languages

- ❖ AMPL
- ❖ GAMS

Hosts

Varied workstations at

- ❖ Aachen University of Technology, Germany
- ❖ Argonne National Laboratory
- ❖ Arizona State University
- ❖ Lehigh University
- ❖ National Taiwan University
- ❖ Universidade do Minho, Portugal
- ❖ University of Wisconsin at Madison

. . . new hosts are readily added anywhere on the Internet

Support

Large mailing list for questions

- ❖ NEOS developers
- ❖ Solver developers

Support request buttons on every page



Observations

Donations

- ❖ Processor cycles
- ❖ Many people's time

Status

- ❖ Limited support
- ❖ No performance guarantees

. . . watch for changes with move to WID

Optimization Services

- ❖ Distributed optimization environment
- ❖ Unified framework of services & utilities for
 - * modeling languages, servers, registries, agents, interfaces, analyzers, solvers, simulation engines
- ❖ Open-source project on COIN-OR

Relevance to cyberinfrastructure

- ❖ A “next generation” NEOS
- ❖ *Defines* standards for all activities necessary to support decentralized optimization on the Internet
- ❖ Embraces distributed computing standards
 - * Extensible Markup Language (XML)
 - * Service Oriented Architecture
 - * Web Services

OS Goals

Conceive optimization as a service

- ❖ Software as a product
 - * in multiple copies on users' machines
- ❖ ***Software as a service***
 - * residing on a server
 - * accessed by numerous client machines over a network

. . . adapted to special challenges

- ❖ Profusion of weak standards for problem description
- ❖ Lack of standards for results, queries, instructions
- ❖ Variety & complexity of information and behavior
- ❖ Disconnect between modeling and solving
 - * mathematical problem types that characterize solvers
 - * model types familiar to customers

OS Framework

Functions

- ❖ Representation of instances, results, and solver options
- ❖ Communication between clients and solvers
- ❖ Registration & discovery of optimization-related services
 - * using the concept of Web Services.

Standards & protocols

- ❖ Representations of model instances
 - * in text files
 - * in memory
- ❖ Interfaces to these representations
 - * `get()`, `set()`, `calculate()` methods
- ❖ Protocols for solver registration & discovery
- ❖ Protocols for client-server communication

OS on the Internet

Home site: `www.optimizationservices.org`

- ❖ Overview, standards, publications, presentations, FAQs
- ❖ Contact information, downloads, licenses

Developer site: `www.coin-or.org/projects/OS.xml`

- ❖ Login, register, wiki, source repository, timeline, search

Newsgroup:

`groups.google.com/group/optimizationservices`

COIN mailing list:

`list.coin-or.org/mailman/listinfo/os`

OS Integration

Core (OSCommon library)

Modeler side

- ❖ AMPL
- ❖ LINGO
- ❖ MATLAB

Solver side

- ❖ COIN OSI
- ❖ AMPL-solver library
- ❖ Linear: CLP, CBC, CPLEX, Impact
- ❖ Nonlinear: IPOPT, LINDO, KNITRO, Bonmin
- ❖ CppAD (automatic differentiation)

OS Repository

Linear (netlib basic, infeasible, Kennington)

- ❖ Individual XML (**OSiL** format) files available now
- ❖ Zip files to come

Mixed integer (mainly from miplib 2003)

Nonlinear

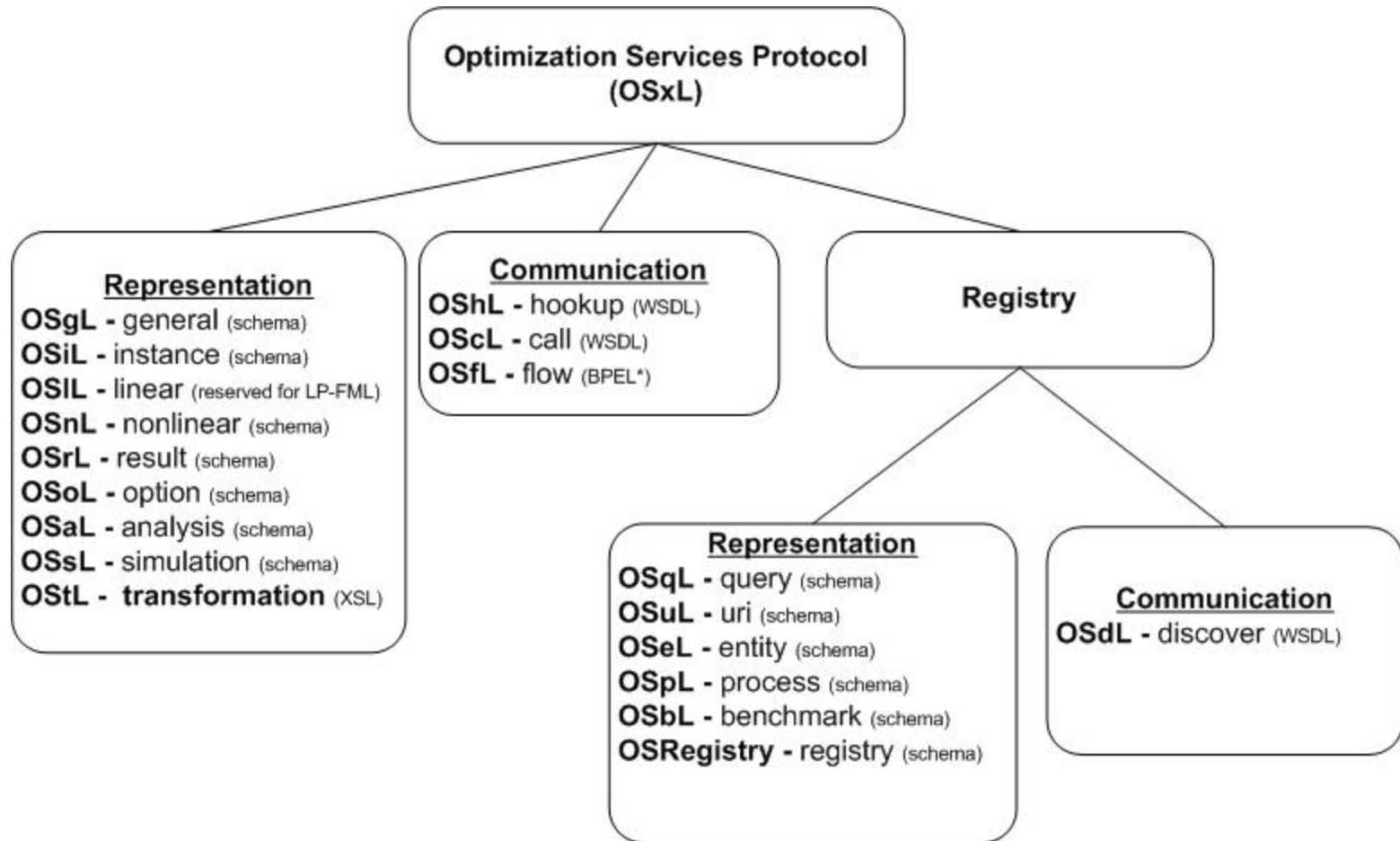
- ❖ CUTE now, more to come

Stochastic

- ❖ Thanks to Gus Gassmann

*. . . all known documentation
(source, solution, description, type, etc.)*

OS Standards



*OSmL: a modeling language and NOT an Optimization Services Protocol

*Letters not currently used: w, z

*BPEL: Business Process Execution Language for flow orchestration.

OSiL: Optimization Problem Instances

Design goals

- ❖ Simple, clean, extensible, object-oriented

Standard problem types supported

- ❖ Linear
- ❖ Quadratic
- ❖ General nonlinear
- ❖ Mixed integer for any of above
- ❖ Multiple objective for any of above
- ❖ Complementarity

OSiL (*cont'd*)

Extensions (stable or near-stable)

- ❖ User-defined functions
- ❖ XML data (within the OSiL or remotely located)
- ❖ Data lookup (via XPath)
- ❖ Logical/combinatorial expressions and constraints
- ❖ Simulations (black-box functions)

OSiL (*cont'd*)

Prototypes

- ❖ Cone & semidefinite programming
- ❖ **Stochastic**
 - * recourse, penalty-based, scenario (implicit or explicit)
 - * risk measure/chance constrained
 - * major univariate, multivariate, user-defined distributions
 - * general linear transformation and ARMA processes
 - * R. Fourer, H.I. Gassmann, J. Ma, and R.K. Martin,
“An XML-Based Schema for Stochastic Programs.”
Forthcoming in *Annals of Operations Research*.

OSrL: Optimization Problem Results

Counterpart to OSiL for solver output

- ❖ General results such as serviceURI, serviceName, instanceName, jobID, time
- ❖ Results related to the solution such as status (unbounded, globallyOptimal, etc.), substatus, message
- ❖ Results related to variables (activities), objectives (optimal levels), constraints (dual values)
- ❖ Service statistics such as currentState, availableDiskSpace, availableMemory, currentJobCount, totalJobsSoFar, timeLastJobEnded, etc.
- ❖ Results related to individual jobs including state (waiting, running, killed, finished), userName, submitTime, startTime, endTime, duration, dependencies, scheduledStartTime, requiredDirectoriesAndFiles.

OSrL (*cont'd*)

Additional solution support

- ❖ Support for non-numeric solutions such as those returned from combinatorial or constraint programming solvers
- ❖ Support for multiple objectives
- ❖ Support for multiple solutions
- ❖ Integration of analysis results collected by the solver

OSoL: Optimization Options

Counterpart to OSiL for solver instructions

- ❖ General options including serviceURI, serviceName, instanceName, instanceLocation, jobID, license, userName, password, contact
- ❖ System options including minDiskSpace, minMemorySize, minCPUSpeed
- ❖ Service options including service type
- ❖ Job options including scheduledStartTime, dependencies, requiredDirectoriesAndFiles, directoriesToMake, directoriesToDelete, filesToCreate, filesToDelete, processesToKill, inputFilesToCopyFrom, inputFilesToCopyTo, etc.

Limited standardization of algorithmic options

- ❖ Currently only initial values

OSoL (*cont'd*)

Including support for:

- ❖ Various networking communication mechanisms
- ❖ Asynchronous communication (such as specifying an email address for notification at completion)
- ❖ Stateful communication (achieved mainly through the built-in mechanism of associating a network request with a unique jobID)
- ❖ Security such as authentication and licensing
- ❖ Retrieving separately uploaded information (when passing a large file as a string argument is inefficient)
- ❖ Extended or customized solver-specific or algorithm-specific options

Other XML Schema-Based Standards

Kept by the OS registry

- ❖ OSeL (entity, experimental): static information on optimization services (such as type, developer)
- ❖ OSpL (process, near stable): dynamic information on optimization services (such as jobs being solved)
- ❖ OSbL (benchmark, experimental): benchmark information on optimization services

For use by the discovery process

- ❖ OSqL (query, experimental): specification of the query format used to discover the optimization services in the OS registry
- ❖ OSuL (uri/url, experimental): specification of the discovery result (in uri or url) sent back by the OS registry

Other Schema-Based Standards (*cont'd*)

Formats and definitions

- ❖ OSsL (simulation, stable): format for input and output used by simulation services invoked via the Optimization Services to obtain function values
- ❖ OSgL (general, near stable): definitions of general elements and data types used by other OSxL schemas. Usually included in the beginning of another OSxL schema through the statement:
`<xs:include schemaLocation="OSgL.xsd"/>`
- ❖ OSnL (nonlinear, stable): definitions (operators, operands, etc.) of the nonlinear, combinatorial, and other nodes used in other OSxL's, mainly OSiL

Other WSDL-Based Standards

WSDL

- ❖ Web Service Definition Language

WSDLs for OS (stable)

- ❖ OShL (hook): for invoking solver/analyzer services
- ❖ OSdL (discover): for invoking optimization registry services to register and discover services
- ❖ OScL (call) for invoking simulation services, usually to obtain function values.

Observations

Contrast to NEOS

- ❖ Lightweight repository only
- ❖ Emphasis on standards

Status

- ❖ Still in formative stages
- ❖ Release 2.2 in open source from COIN-OR

. . . binary distributions also available

Intelligent Optimization Systems

Beyond repositories and registries

- ❖ Interactive aids to modeling
- ❖ Automatic connection of modelers to solvers

Relevance to cyberinfrastructure

- ❖ Missing link in optimization as a service

Interactive Aids to Modeling

ANALYZE (Greenberg)

- ❖ Alternative views
- ❖ Simplification
- ❖ Rule-based reporting
- ❖ Extended sensitivity analysis
- ❖ Infeasibility diagnosis

MProbe (Chinneck)

- ❖ Analyze feasibility, redundancy, constraint effectiveness
- ❖ Tighten bounds, find near-feasible points
- ❖ Plot functions
- ❖ Analyze function shape (convex? concave? almost linear?)
- ❖ Estimate shape of constrained region (convex?)
- ❖ Estimate function range and slope
- ❖ Estimate objective effect (global? local?)

MProbe Example (1)

Variables Workshop 10 of 17 variables visible

Show only > type: real Reverse Selection

name	i.d.	type	no. funcs	orig lwr bnd	temp lwr bnd	sel. obj. best point	temp upr bnd	orig upr bnd	lwr bnd
x	0	Real	5	-1.E+02	-1.E+02	1.307498E-01	1.E+02	1.E+02	Red
y	1	Real	5	-1.E+02	-1.E+02	3.024638E+00	1.E+02	1.E+02	Red
mt1	6	Real	3	-1.E+00	-1.E+00	8.136667E-01	1.E+00	1.E+00	Nec
mt2	7	Real	1	-1.E+00	-1.E+00	2.635834E-01	1.E+00	1.E+00	Nec
sinqquad2	5	Real	1	-1.E+01	-1.E+01	-8.351681E+00	1.E+01	1.E+01	Red
sinqquad1	4	Real	1	-1.E+01	-1.E+01	9.231597E+00	1.E+01	1.E+01	Red
z2	3	Real	1	-1.E+01	-1.E+01	6.659936E+00	1.E+01	1.E+01	Red
z1	2	Real	1	-1.E+01	-1.E+01	3.470179E+00	1.E+01	1.E+01	Red
sinp1	10	Real	0	0.E+00	0.E+00	6.348978E+01	1.E+02	1.E+02	Red
sinp2	11	Real	0	0.E+00	0.E+00	8.131882E+01	1.E+02	1.E+02	Red

Sort on selected column(s) > descending Show Value > Sel. obj. best point

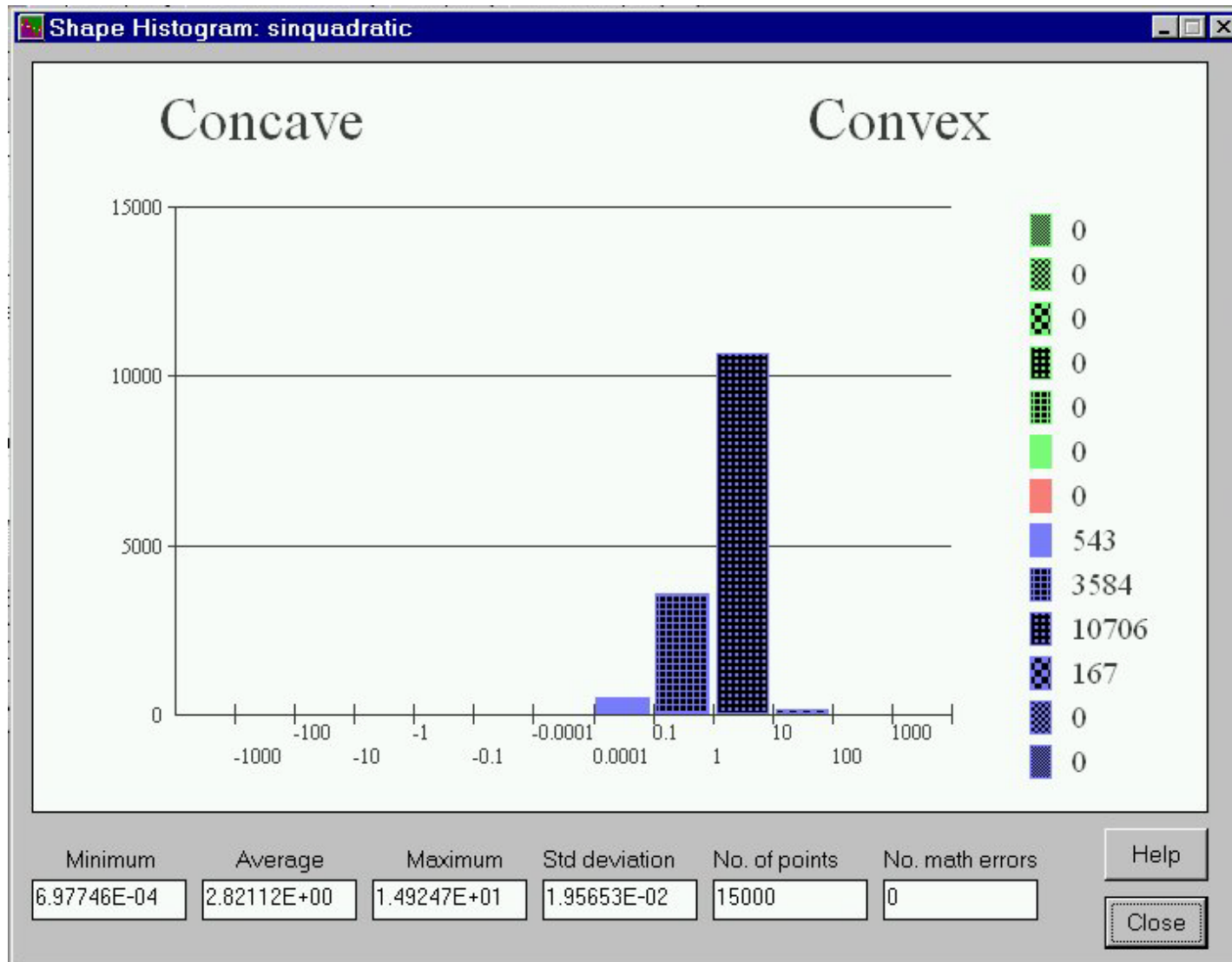
Freeze variable names/i.d. Trace

Perform Action >

- change bound on selected variable
- change bound on selected variable
- change bounds on visible group
- reset original bounds
- show constraints containing selected variable**
- show objectives containing selected variable
- replace current bounds with max/min sampled values

Help Exit

MProbe Example (2)



Automatic Connection to Solvers

DrAMPL (Orban & Fourer)

- ❖ Process model written in AMPL language
- ❖ Determine type of problem instance
 - * Linear, quadratic, nonlinear
 - * Continuous, differentiable, integer
 - * Unconstrained, bounded, constrained
 - * Convex, concave
- ❖ Compare against database of solver abilities
- ❖ Recommend choice of solver

. . . some obvious, some difficult

Example (“Dr. AMPL”)

Analysis

Problem type

- Problem has bounded variables
- Problem has no constraints

Analyzing problem using only objective

- This **objective is quadratic**
- Problem is a QP with bounds

-0.833013 <= objective <= 0.8359

Problem convexity

Nonlinear **objective looks convex on its domain.**

Detected 0/0 nonlinear convex constraints,
0/0 nonlinear concave constraints.

Example (“Dr. AMPL”)

Solver recommendations

```
### Specialized solvers, based on all properties ###  
  
    MOSEK  
    OOQP  
  
### Specialized solvers, excluding "hard" properties ###  
  
    BLMVM  
    FortMP  
    L-BFGS-B  
    MINLP  
    MOSEK  
    OOQP  
    PathNLP  
    SBB  
    TRON  
  
### General-purpose solvers ###  
  
    KNITRO  
    LANCELOT  
    LOQO
```

Challenges

Detection & transformation

- ❖ Identify tractable problem types
- ❖ Convert to forms that solvers can handle
- ❖ Convert the results back

Examples

- ❖ Generalized variable domains
 - * arbitrary unions of points & intervals
- ❖ Separable piecewise-linear functions
- ❖ Complementarity constraints
- ❖ Logical and combinatorial constraints
 - * $\langle c1 \rangle$ or $\langle c2 \rangle$, $\langle c1 \rangle$ implies $\langle c2 \rangle$
 - * counting, all-different
- ❖ Second-order cone constraints

Cyberinfrastructure for Optimization

Advanced computing resources

Cloud computing

Advanced Computing Resources

Platforms offering special power

- ❖ Multiple processors
- ❖ Huge storage devices
- ❖ Fast networks

. . . and algorithms to take advantage of them

Relevance to cyberinfrastructure

- ❖ Facilitates many uses — sometimes unanticipated
- ❖ Infrastructure already in existence
 - * supercomputer centers
 - * computational grids

Types of Advanced Computing

High-performance computing

- ❖ Large numbers of specialized processors
- ❖ Specialized interconnections

Distributed computing (MW)

- ❖ Standard computers
- ❖ Working together through Internet connections

High-throughput computing (Condor)

- ❖ Otherwise idle computers
- ❖ Networked by special software

Sample Research

From the metaNEOS project (1997–2001)

- ❖ 1010-variable deterministic equivalent of a 107-scenario stochastic program on a computational grid of about 800 workstations, in about 32 hours of wall-clock time
- ❖ a previously intractable quadratic assignment problem using an average of 650 worker machines over a one-week period, providing the equivalent of almost 7 years of computation on a single workstation
- ❖ a mixed-integer nonlinear programming problem with parallel efficiency of up to 80% on 600 million search-tree nodes

Resulting Applications

Essentially none

- ❖ Impractical to write new software for each application
- ❖ No access to software from previous studies

Needs

Advanced computing + software services

- ❖ Put optimization software on high-performance platforms
- ❖ Make it generally available through NEOS or OS

Advanced computing for optimization

- ❖ Solving on demand
- ❖ Flexible resource allocation

. . . a new paradigm

Cloud Computing

Current significance

- ❖ Software-as-a-service by another name
- ❖ Cyberinfrastructure for building software services

What it means for optimization providers

- ❖ Coordination
 - * NEOS scheduler
 - * OS registry
- ❖ Resources
 - * Windows Azure
 - * IBM's various options
 - * Amazon EC2

Cloud Coordination

NEOS

- ❖ Central *registry*
- ❖ Central *scheduler*
- ❖ You supply solvers and hardware

OS

- ❖ Central *registry* only
 - ❖ You supply scheduler, solvers and hardware
- . . . lighter-weight solution*

Cloud Resources

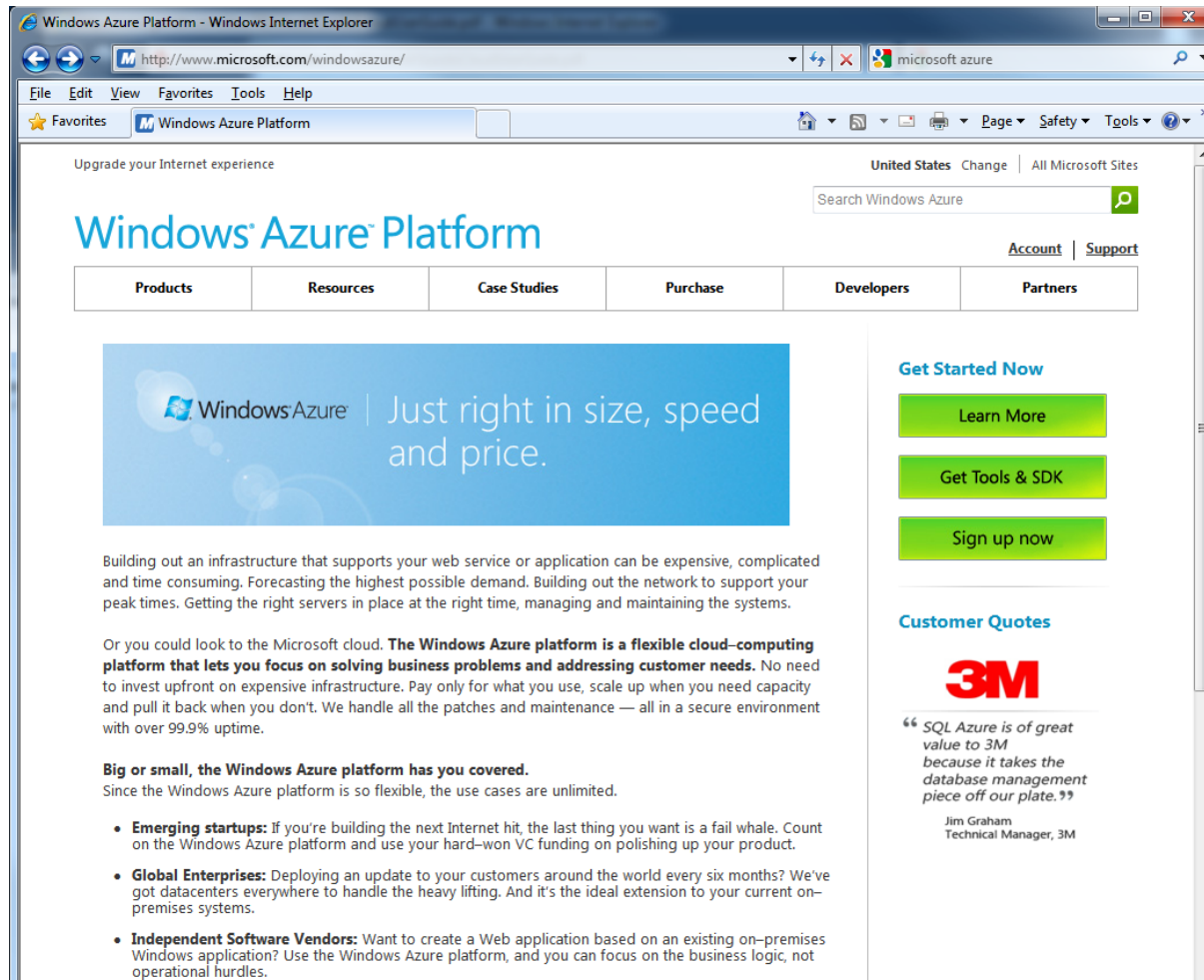
Several commercial offerings

- ❖ Central *hardware*
- ❖ Central *development software*
- ❖ You supply solvers

Current examples . . .

Cloud Resources (1)

Microsoft Windows Azure



Upgrade your Internet experience

United States Change | All Microsoft Sites

Search Windows Azure

Account | Support

Products	Resources	Case Studies	Purchase	Developers	Partners
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Windows Azure | Just right in size, speed and price.

Building out an infrastructure that supports your web service or application can be expensive, complicated and time consuming. Forecasting the highest possible demand. Building out the network to support your peak times. Getting the right servers in place at the right time, managing and maintaining the systems.

Or you could look to the Microsoft cloud. **The Windows Azure platform is a flexible cloud-computing platform that lets you focus on solving business problems and addressing customer needs.** No need to invest upfront on expensive infrastructure. Pay only for what you use, scale up when you need capacity and pull it back when you don't. We handle all the patches and maintenance — all in a secure environment with over 99.9% uptime.

Big or small, the Windows Azure platform has you covered.
Since the Windows Azure platform is so flexible, the use cases are unlimited.

- **Emerging startups:** If you're building the next Internet hit, the last thing you want is a fail whale. Count on the Windows Azure platform and use your hard-won VC funding on polishing up your product.
- **Global Enterprises:** Deploying an update to your customers around the world every six months? We've got datacenters everywhere to handle the heavy lifting. And it's the ideal extension to your current on-premises systems.
- **Independent Software Vendors:** Want to create a Web application based on an existing on-premises Windows application? Use the Windows Azure platform, and you can focus on the business logic, not operational hurdles.

Get Started Now

Learn More

Get Tools & SDK

Sign up now

Customer Quotes

3M

“SQL Azure is of great value to 3M because it takes the database management piece off our plate.”

Jim Graham
Technical Manager, 3M

*Excel Solver
for the Cloud
... coming soon?*

Cloud Resources (2)

IBM solutions, technologies, consulting, design



Many offerings . . .

*CPLEX
not there yet*

Cloud Resources (3)

Amazon EC2

Amazon Elastic Compute Cloud (Amazon EC2) - Windows Internet Explorer

http://aws.amazon.com/ec2/

File Edit View Favorites Tools Help

Amazon Elastic Compute Cloud (Amazon EC2)

amazon web services

Sign in to the AWS Management Console | Create an AWS Account | English

AWS Products Developers Community Support Account

Products & Services

Amazon Elastic Compute Cloud (Amazon EC2)

Amazon Elastic Compute Cloud (Amazon EC2) is a web service that provides resizable compute capacity in the cloud. It is designed to make web-scale computing easier for developers.

Amazon EC2's simple web service interface allows you to obtain and configure capacity with minimal friction. It provides you with complete control of your computing resources and lets you run on Amazon's proven computing environment. Amazon EC2 reduces the time required to obtain and boot new server instances to minutes, allowing you to quickly scale capacity, both up and down, as your computing requirements change. Amazon EC2 changes the economics of computing by allowing you to pay only for capacity that you actually use. Amazon EC2 provides developers the tools to build failure resilient applications and isolate themselves from common failure scenarios.

[Sign Up For Amazon EC2](#)

This page contains the following categories of information. Click to jump down:

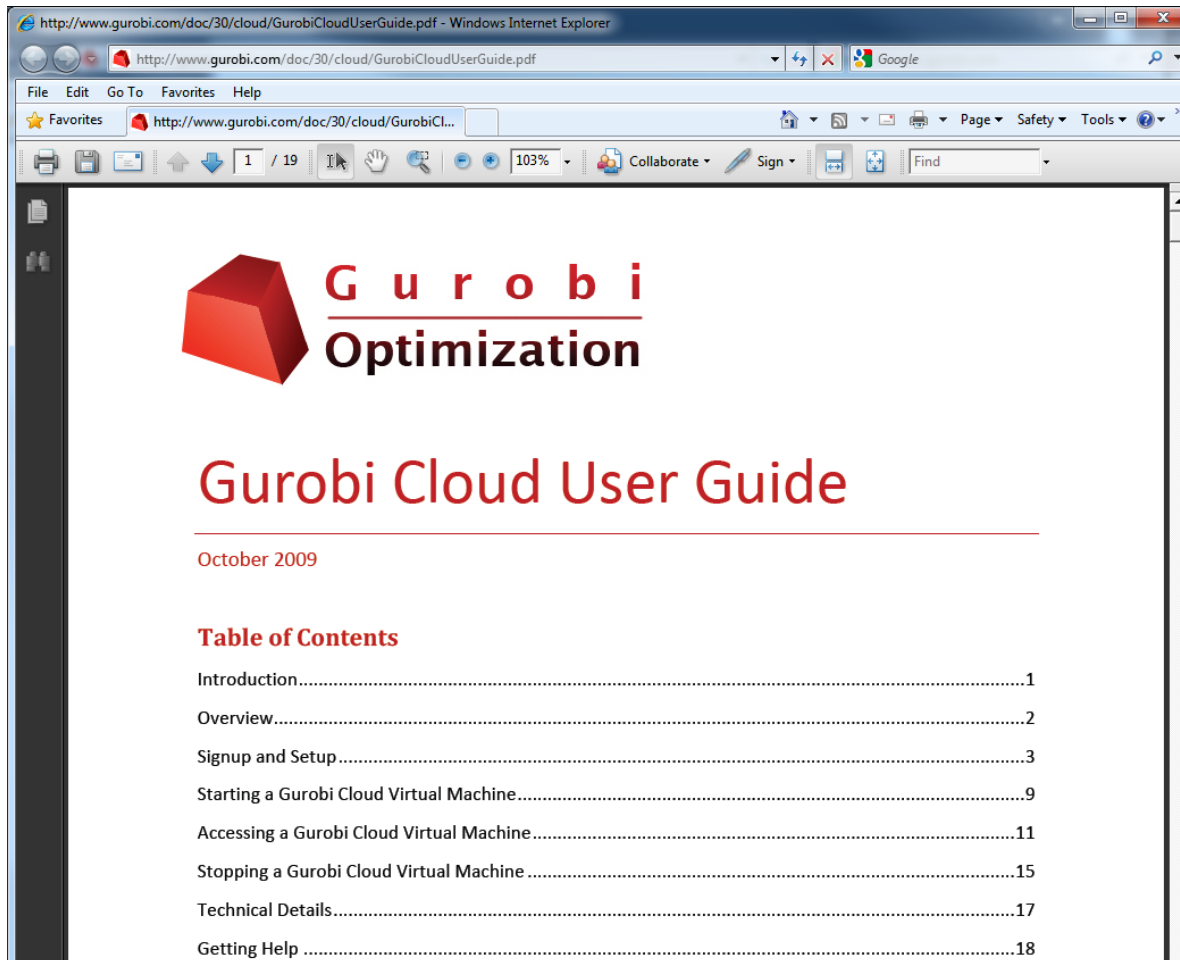
- ↓ [Amazon EC2 Functionality](#)
- ↓ [Pricing](#)
- ↓ [Service Highlights](#)
- ↓ [Resources](#)
- ↓ [Features](#)
- ↓ [Detailed Description](#)
- ↓ [Instance Types](#)
- ↓ [Intended Usage and Restrictions](#)
- ↓ [Operating Systems and Software](#)

Amazon EC2 Functionality

Amazon EC2 presents a true virtual computing environment, allowing you to use web service interfaces to launch

Cloud Resources (3)

Gurobi solver on Amazon EC2




http://www.gurobi.com/doc/30/cloud/GurobiCloudUserGuide.pdf - Windows Internet Explorer

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Gurobi
Optimization

Gurobi Cloud User Guide

October 2009

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Cloud Resources (3)

Gurobi solver on Amazon EC2 (prices)

The screenshot shows a web browser window displaying the Gurobi Optimization website. The page is titled "Download :: Price List" and shows the user's menu, today's date (August 27, 2010), and the user's name (Robert Fourer). The main content area is titled "Pricing" and "Gurobi Optimizer". Under "Cloud Licenses", there is a section for "EC2 Cloud Server - Unlimited-User, Single Machine License". This section describes the license and provides pricing for three instance types: High-Memory Extra Large Instance (\$4 per hour), High-Memory Double Extra Large Instance (\$6 per hour), and High-Memory Quadruple Extra Large Instance (\$8 per hour).

Instance Type	Price
High-Memory Extra Large Instance	\$4 per hour
High-Memory Double Extra Large Instance	\$6 per hour
High-Memory Quadruple Extra Large Instance	\$8 per hour

Cloud Optimization **Prices**

Gurobi prices

- ❖ High-memory extra-large instance **\$4/hour**
- ❖ High-memory double extra-large instance **\$6/hour**
- ❖ High-memory quadruple extra-large instance **\$8/hour**
- ❖ Data transfer in or out **\$0.20/gigabyte**

General principles

- ❖ Rent machine time, not CPU time
- ❖ Adaptable to mixed modeling and solving

Practical issues

- ❖ Will there be day, week, month discounts?
- ❖ How can both a modeling system and solver be provided?

. . . need to divide the revenues