

High Productivity Computational Finance on GPUs

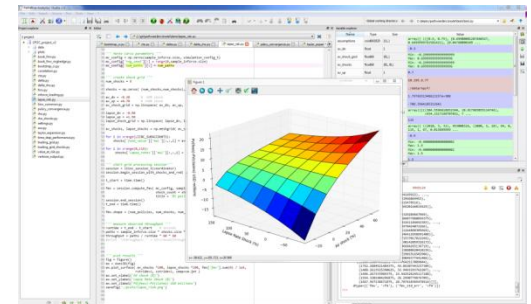
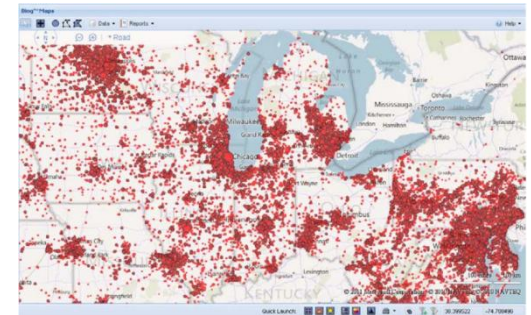
GPU Technology Conference
March 15, 2012

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- Industry leading software and infrastructure and expertise means improved risk management, lower costs and better hedge program results
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- Unique ability to work with clients to review and improve candidate investment bank structured solutions
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PathWise™ Platform

- The fastest, most scalable, and integrated high performance computing based variable annuity risk management platform in the industry
- Platform includes tools for hedging, pricing, and the calculation and forecasting of capital and reserves
- Guaranteed run-times and performance

Consulting Services

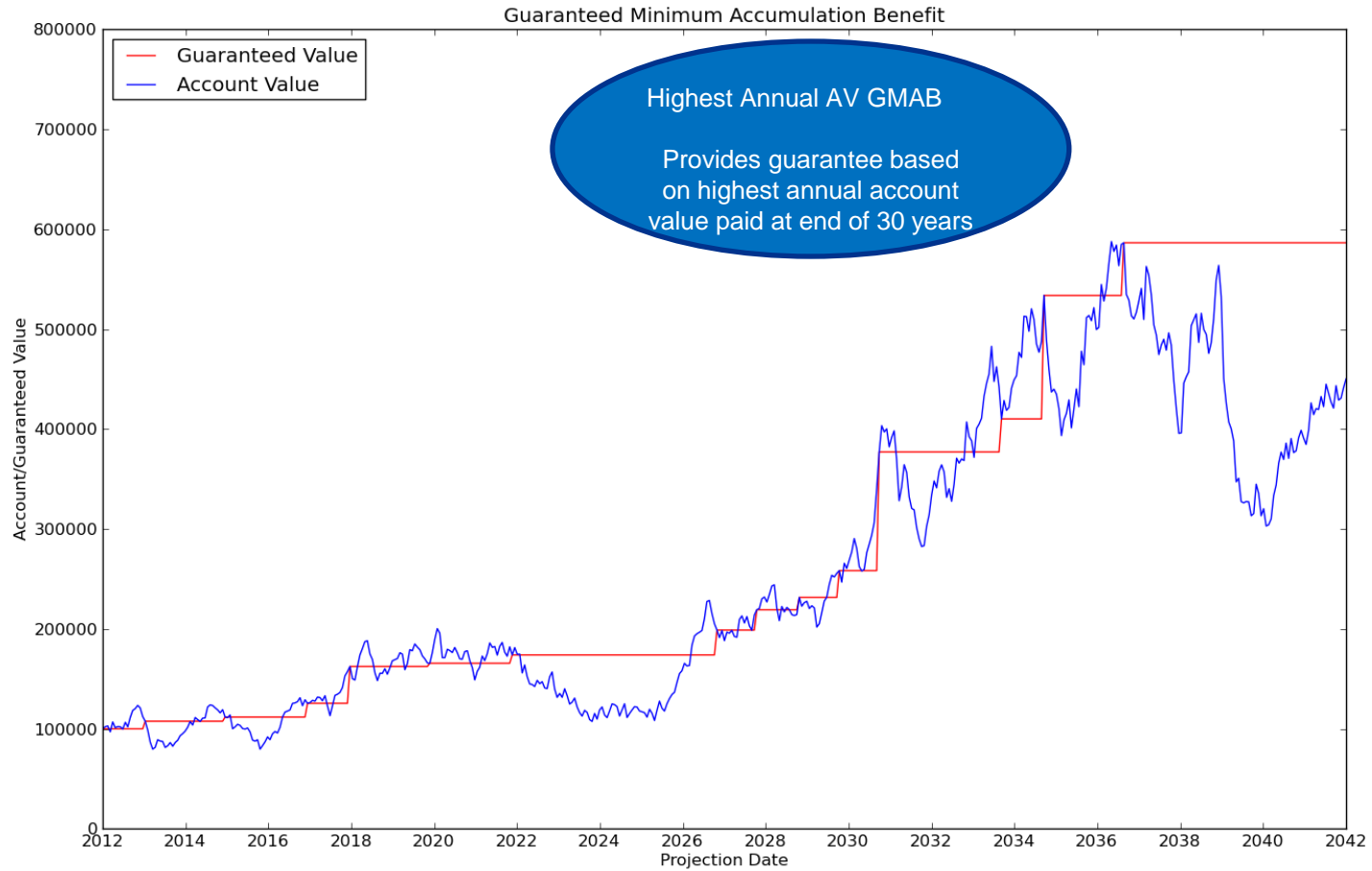
- Analysis of reinsurance and investment banking solutions
- VA Liability and hedge asset stochastic on stochastic modeling
- Performance Attribution, Grouping, Fund Mapping, etc
- Hedge strategy development and testing

- 40+ years of modeling, derivatives trading and risk management experience
- A tightly knit, uniquely knowledgeable team combining financial, software, high performance computing and insurance and capital markets expertise

Industry Overview

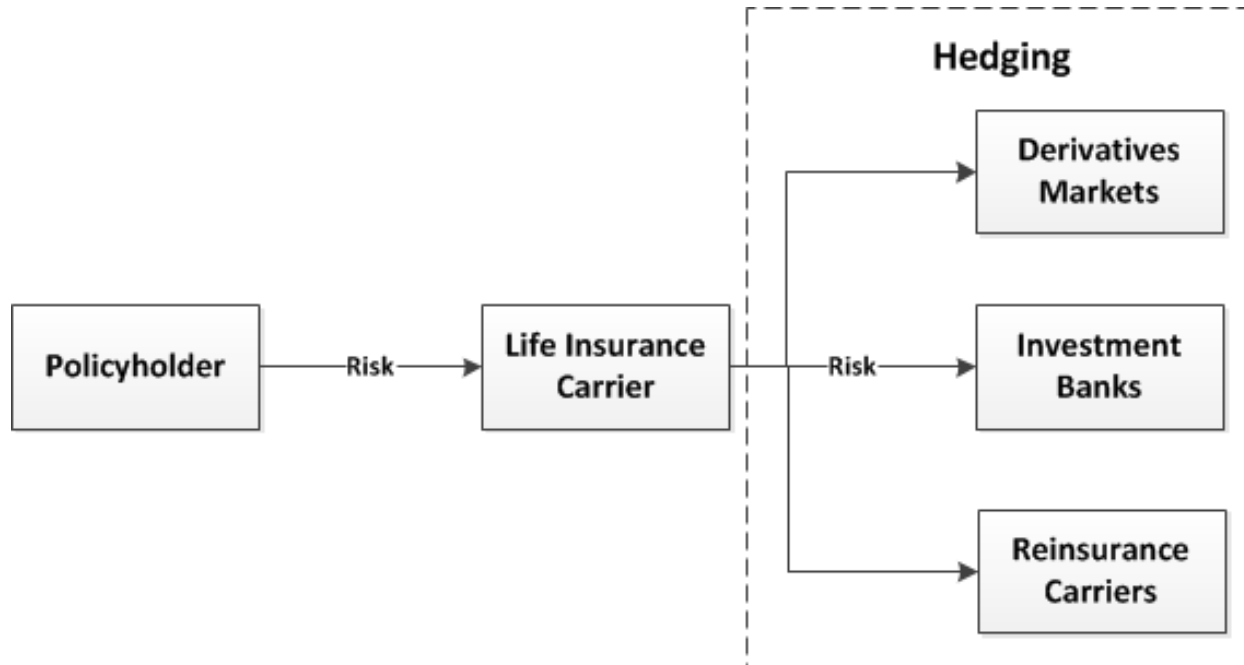
- Life Insurance companies sell Retirement Savings products to individual policyholders
- Since the early 1990's, these products have evolved into **complex Investment Guarantees** that protect policyholders against three main types of risks:
 - Mortality risk (risk of death)
 - Longevity risk (risk of outliving retirement funds)
 - Investment risk (risk of financial losses)
- Variable Annuity assets in North America currently exceed **\$1.5 trillion.**
- Examples of popular products by region:
 - Europe
 - With Profits (UK)
 - Equity Indexed Annuities (EIAs)
 - North America, Japan, South Korea
 - Variable Annuities (VAs)

Industry Overview



Industry Overview

- Insurance companies must **hedge** the systematic or non-diversifiable market risks associated with these products



Industry Overview

- Common hedging instruments

		Hedging Instruments							
		Equity Futures	Interest Rate Swaps	Variance Swaps	Vanilla Options	Hybrid Options	Lookback Options	Structured Hedge	Reinsurance
Risks	Delta	✓			✓	✓	✓	✓	✓
	Rho		✓		✓	✓	✓	✓	✓
	Vega			✓	✓	✓	✓	✓	✓
	Gamma			✓	✓	✓	✓	✓	✓
	Vanna						✓	✓	✓
	Vol Skew						✓	✓	✓
	Correlation							✓	✓
	Policyholder Behavior								✓
	Basis Risk								✓

Industry Computational Challenges

Industry Computational Challenges

- **Business end-users focus**

- ♦ Users are Quantitative Analysts, Actuaries, Traders, Risk Managers, etc
- ♦ The right tools must focus on the end-user requirements

- **Business logic and systems code must be continually adapted to changes**

- ♦ Changing models, financial products, market conditions, and regulatory requirements
- ♦ Changing technologies (Multi-Core, Cell Broadband Engine, GPUs, etc)

- **High Computational Throughput is required**

- ♦ Large-scale real-time Monte Carlo simulations (Support Hedging Programs)
- ♦ Nested simulations (Hedging Back Testing, Capital, Valuation)
- ♦ High end-user productivity (not waiting for huge runs to complete)

- **Mission Critical Operations**

- ♦ The intended use of such systems is mission critical
- ♦ System failures or bugs can be catastrophic for business users
- ♦ Automation and auditability are very important issues

Industry Computational Challenges

- **Business end-users focus**

- Actuarial and quantitative financial analytics are extremely complex. As example, we consider the model specifications for one of the simplest stochastic models that we use in PathWise:

$$\begin{aligned}\frac{dS_t}{S_t} &= r_t dt + \sqrt{v_t} dW_t^{S,1} + \gamma dW_t^{S,2} \\ dv_t &= \alpha(\theta(t) - v_t) dt + \eta(t) \sqrt{v_t} dW_t^v, \\ dr_t &= \beta(\phi(t) - r_t) dt + \sigma(t) dW_t^r,\end{aligned}$$

$$\begin{aligned}\mathbb{E}^{\mathbb{Q}^T} [(X_T - K)_+] &= \overbrace{X_0 \Phi(d_+) - K \Phi(d_-)}^{\text{zero vol-vol price}} \\ &+ \underbrace{\frac{\sqrt{K X_0}}{\pi} \int_0^{+\infty} \Re \left(e^{-iz \log(K)} \frac{\bar{\varphi} \left(z - \frac{1}{2}i \right) - \varphi \left(z - \frac{1}{2}i \right)}{z^2 + \frac{1}{4}} \right) dz}_{\text{stochastic vol correction}},\end{aligned}$$

- These types of model specifications are not easily understood by traditional programmers or IT business analysts. Understandably, business end-users prefer to implement models themselves (e.g using Excel and VBA)

Industry Computational Challenges

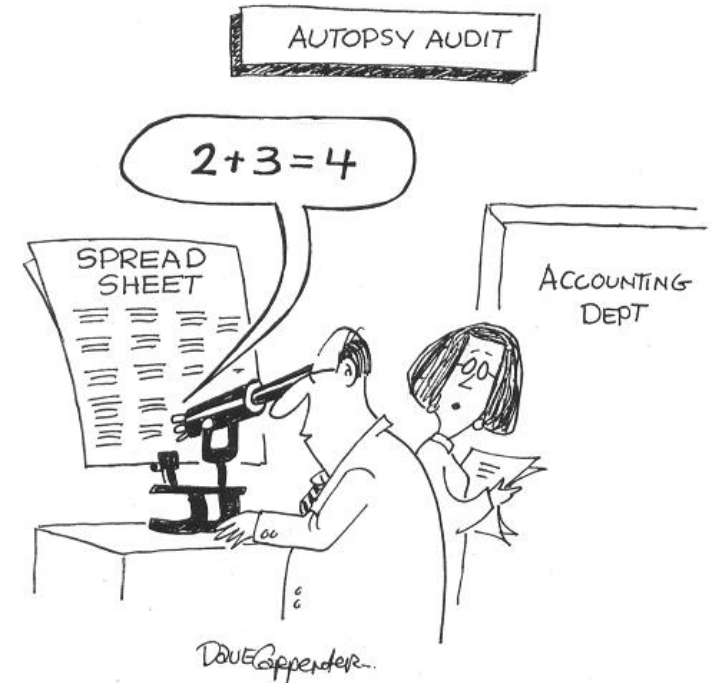
- **Business logic and systems code must be continually adapted to changes**

- Change is constant

- Financial modeling innovation
- Financial products innovation
- Evolving market conditions
- Changing regulatory requirements
- Technological innovation

- Traditional approaches

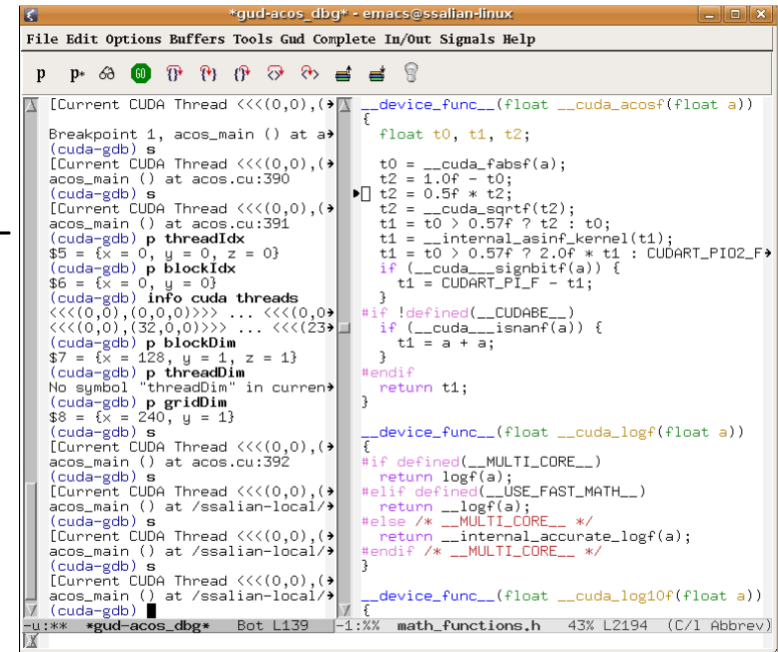
- Enterprise IT systems slow to adapt
- Shadow IT systems fill the gaps - patchwork of end-user developed, manually operated spreadsheets (potentially thousands of interlinked spreadsheets)
- Slow, costly, error-prone



"There it is! I've isolated the origin of the firm's demise."

Industry Computational Challenges

- **High Computational Throughput is required**
 - GPU grid and/or cloud is an excellent solution
 - But GPU grid / cloud is difficult to program
 - Teams of end-users programming GPUs in low-level languages such as CUDA or C++ is suboptimal
 - Huge complexity added by attempting to scale to distributed systems (clusters, cloud)
 - General purpose, high level languages
 - Helpful only to a point
 - Development effort is not significantly reduced (end-users must still somehow architect and implement a highly complex software system)
 - Severe limitations and performance bottlenecks may be inadvertently introduced



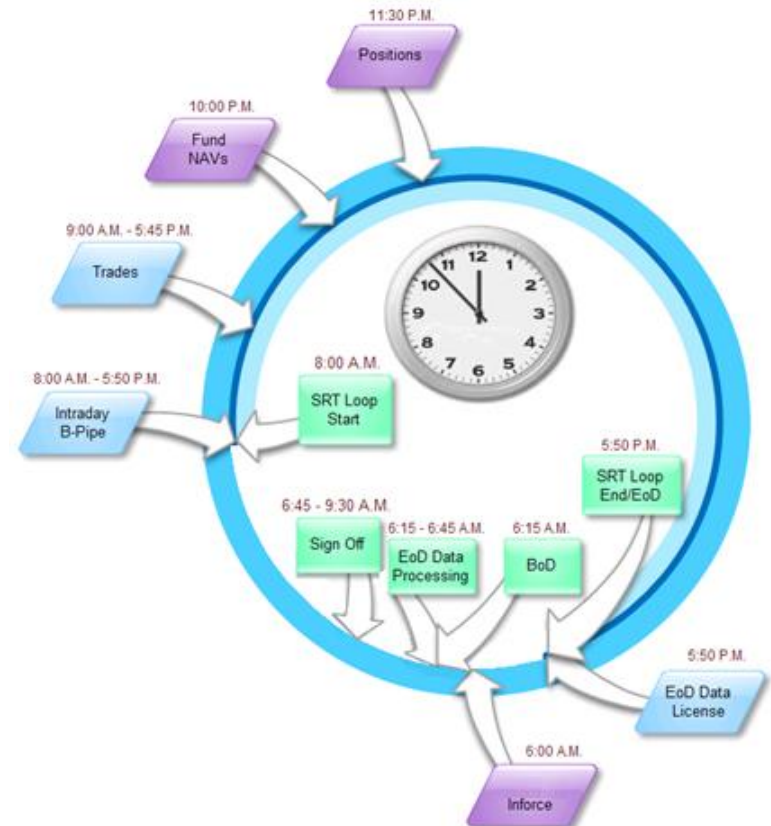
The screenshot shows a debugger window titled '*gud-acos_dbg*' - emacs@ssalian-linux. The window contains a list of commands and their outputs for a CUDA program. The commands include setting breakpoints, stepping through the code, and inspecting variables like threadIdx, blockDim, and gridDim. The code being debugged is a C++ function for calculating the arccosine of a float value, using CUDA-specific functions like __cuda_fabsf, __cuda_sqrtf, and __internal_asinf_kernel. The debugger also shows the current thread's state and the location of the code in the source file 'math_functions.h'.

Industry Computational Challenges

▪ Mission Critical Operations

– Requirements

- Complex business data-flow management
 - Job scheduling
 - Fault tolerance / failover
 - Operational workflows
 - Reporting presentation layers
 - Audit trails
 - Monitoring and Error Reporting
- Not just about implementing CUDA kernels



Industry Computational Challenges

▪ Application Stack

Who	What	Examples
End-users	Presentation Layer	Queries, reports, visualization, real-time dashboards
	Business Logic	Data structures, models, business rules
Software Developers	Application support	Training, documentation, troubleshooting
	Application deployment	Application updates, configuration, version management
	Application development	Frameworks, GUI, system-level code, CUDA kernels
	Middleware	Grid middleware, messaging, web services
	Databases	SQL, NoSQL (MapReduce), etc
Engineers / IT Admins	Infrastructure operations	Security, systems monitoring, maintenance
	Operating Systems	Linux, Windows
	Virtual Machines	Citrix, VMWare, Amazon Elastic Compute Cloud
	Servers	Rack-mount (1-4U), blade server, proprietary rack
	Processors	CPU, GPU, FPGA, Hybrid, ASIC
	Storage	SAN, file servers, SSDs
	Network	1GigE, 10GigE, InfiniBand
	Data Center	On-premise, co-location, cloud, garage

Industry Computational Challenges

	Layer	In-House App Development	Outsourced Blackbox Solution	PathWise SaaS option
End-users	Presentation Layer	✓	✗	✓
	Business Logic	✓	✗	✓
Software Developers	Application support	✓	✗	✗
	Application deployment	✓	✗	✗
	Application development	✓	✗	✗
	Middleware	✓	✗	✗
	Databases	✓	✗	✗
Engineers / IT Admins	Infrastructure operations	✓	✓	✗
	Operating Systems	✓	✓	✗
	Virtual Machines	✓	✓	✗
	Servers	✓	✓	✗
	Processors	✓	✓	✗
	Storage	✓	✓	✗
	Network	✓	✓	✗
	Data Center	✓	✓	✗

Legend	
✓	Implemented by end-users (good)
✓	Implemented by end-users (bad)
✗	Not implemented by end-users (good)
✗	Not implemented by end-users (bad)

Industry Computational Challenges

▪ In-house software development (roll your own)

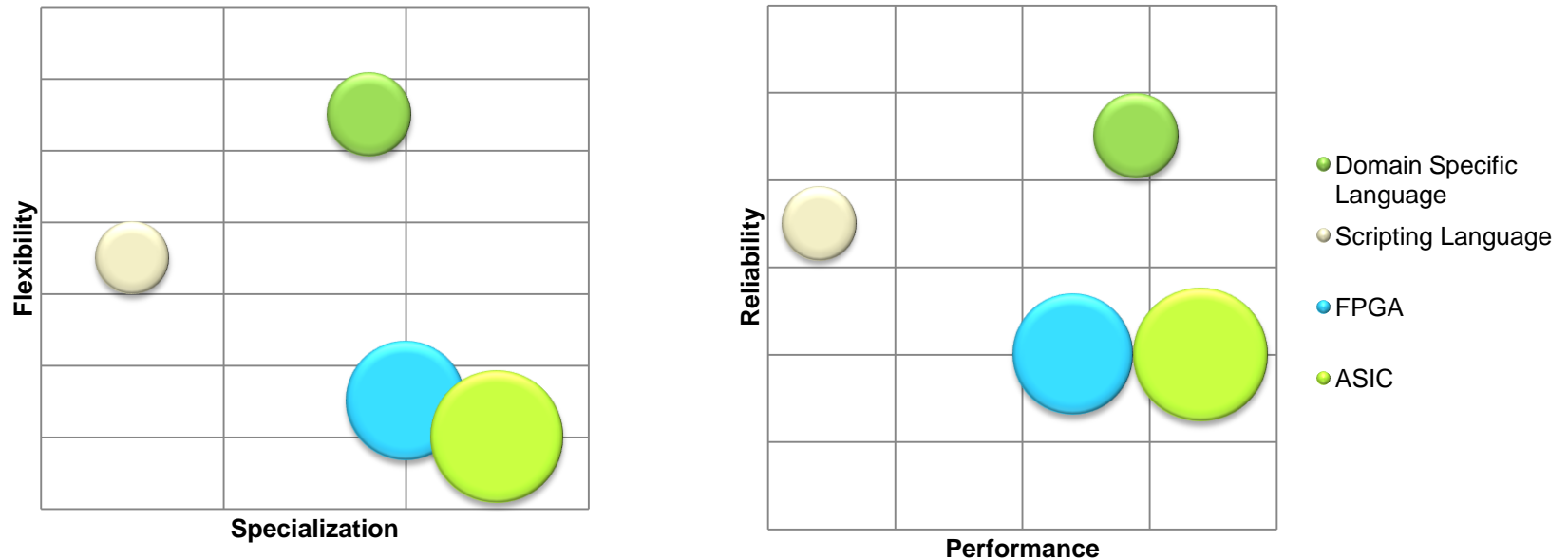
- High risk project for organizations that do not have extensive expertise in commercial software development
 - Costly and time consuming even for experts
- Limited functionality and innovation roadmap
 - High-end solutions, such as nested Monte Carlo simulation and high productive end-user tools, remain out-of-reach
- Long-term costs of maintaining such systems, under continual business change, are often underestimated

▪ Software development outsourcing

- Difficulty understanding business requirements and scope
- Language, cultural, and geographical barriers
- High complex requirements (e.g. quantitative finance, scientific codes, etc) are not easily understood by programmers
- Quality Assurance, Support and Security issues

Industry Computational Challenges

Example HPC Solution Trade-Offs



Size of bubble indicates cost (in terms of time and money) of solution

- **Flexibility** – ability to rapidly make changes
- **Specialization** – code specialized to specific hardware
- **Performance** – run-time performance of the solution
- **Reliability** – probable number of bugs in a large system

PathWise Platform



PathWise Platform

▪ PathWise Solution

– Domain Specific Visual Programming Language

- Generates C++/CUDA code (double and single precision)
- Generates middleware interfaces
- Spreadsheet-like interface for entering computation logic
- SVN integration

– Data Management Solution

- Message-oriented persistent storage system
- Specialized for dealing with numerical / financial data

– Python Integration

- High-level APIs for steering grid computations, accessing business data, visualizing results, and creating reports

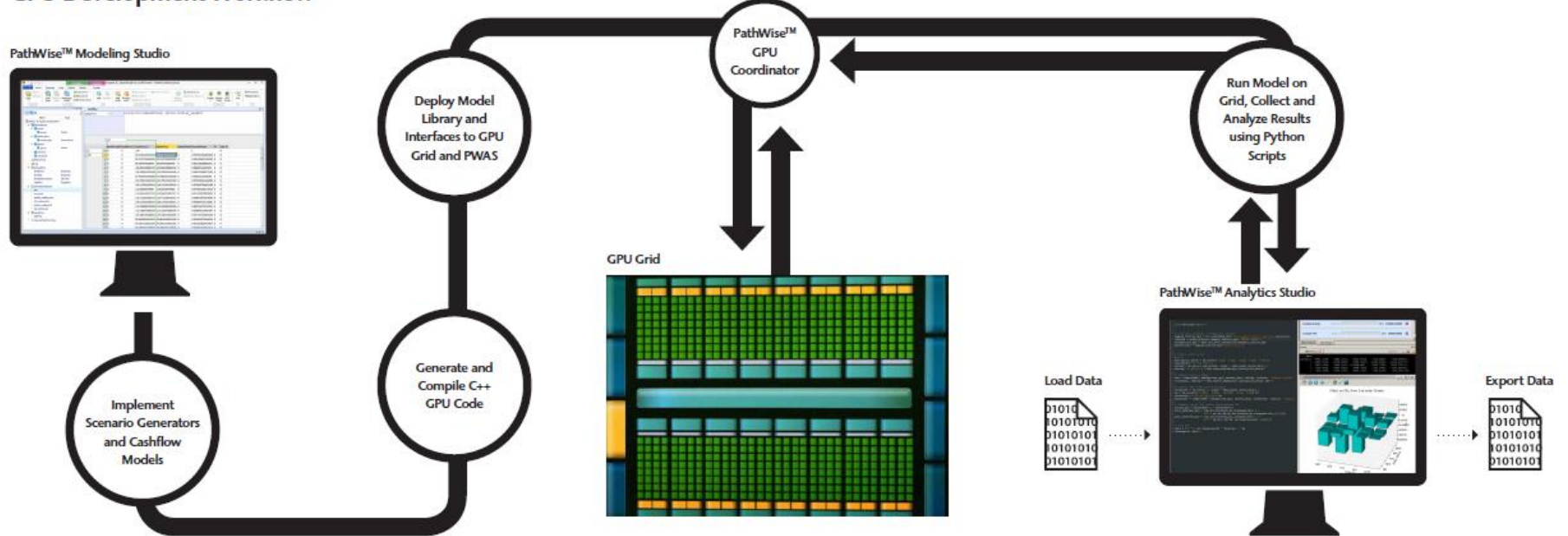
– Platform-as-a-Service offering and Cloud Integration

- End-to-End management solution
- Amazon EC2 integration

PathWise Platform

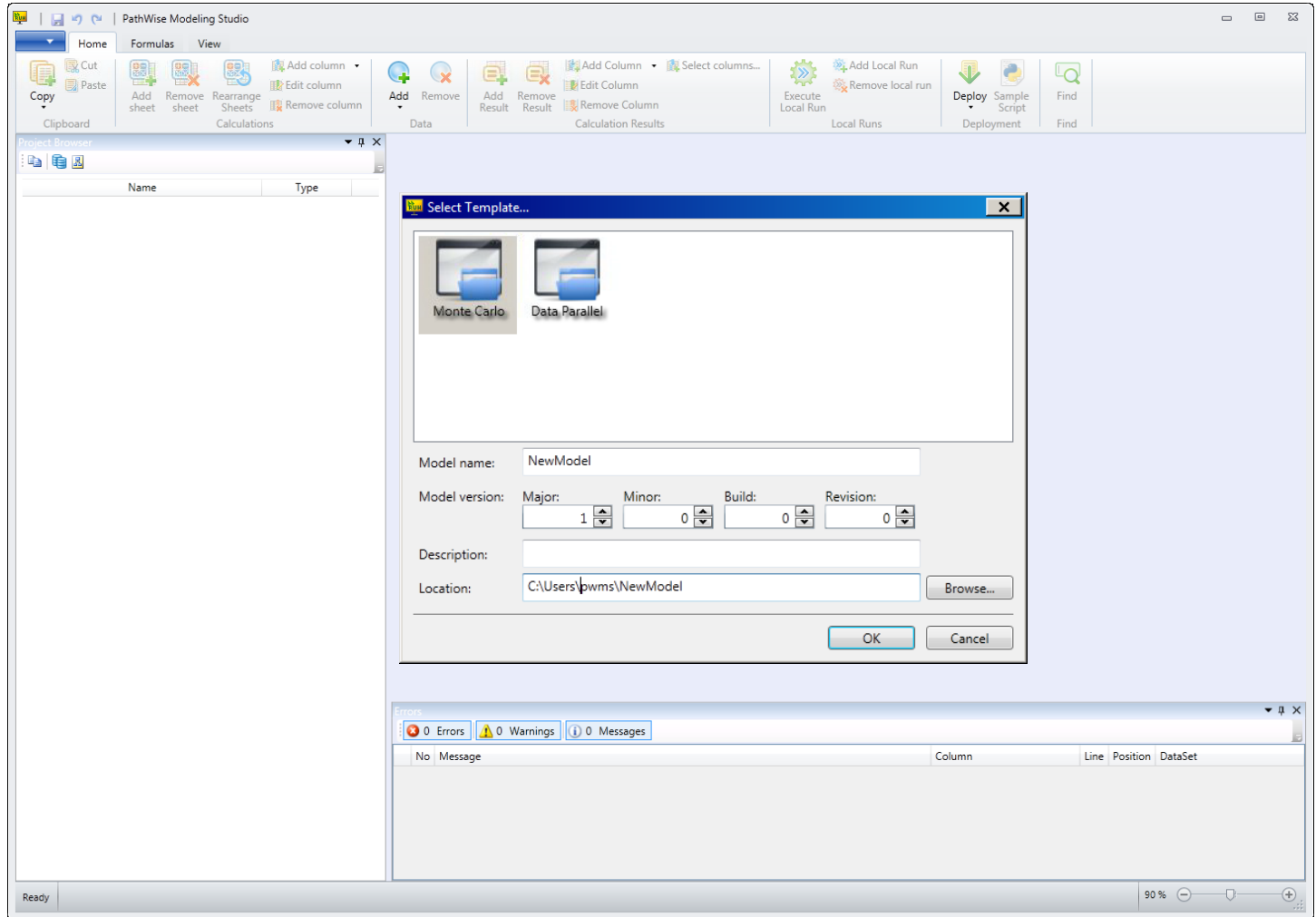
- End-user tools for High Productivity Computing

GPU Development Workflow



PathWise Modeling Studio

- Create a new model



PathWise Modeling Studio

- Define input data structures (customized NumPy data structures)

The screenshot displays the PathWise Modeling Studio interface. The main window shows a project browser on the left with a tree view of data sources and assumptions. The central pane displays a table of data for 'mortality_tables' with columns for 'mortality_table_id', 'age', and 'Qt'. The 'Add/Edit Data Set' dialog box is open, showing the following configuration:

- Add/Edit Data Set:**
 - Name: mortality_tables
 - Type: Assumptions
 - Alias: (empty)
 - Array Size: Fixed (selected)
 - Update formulas:
- Data Source:**
 - Name: model_data
 - Path: C:\Documents\pwms\GMMB\data\model_data.npz
- Schema options:**
 - Shape: 2
 - Precision: Float (selected)
 - Array type: Structure (selected)
 - Type: (empty)
- Table:**

Name	Type	Shape	Shock
mortality_table_id	int		None
age	int	116	None
Qt	real	116	Auto

DType:
[[('mortality_table_id', '<i4'), ('age', '<i4', (116L)), ('Qt', '<f4', (116L))]]

PathWise Modeling Studio

- Setup Random Number Generator options

The screenshot shows the PathWise Modeling Studio interface with the 'RNG Configuration' dialog box open. The dialog is titled 'seed' and contains the following configuration options:

- seed:** =inforce.rng_seed
- Configuration:**
 - Num paths: =inforce.num_paths
 - Skip rows: =0
 - Current path index: < 0 >
- Uniform Generator Params:**
 - Uniform Generator: XORWOW Pseudo-random Generator (selected)
 - Seed: =inforce.rng_seed
- Distribution Algorithm:** Mersenne Twister (607) Pseudo-random Generator
- Non-Central Chi Square:** Sobol (32) Quasi-random Generator, Sobol (64) Quasi-random Generator, Minimal Random Generator, CURAND MTGP11213 Generator, CURAND MRG32K3A Generator
- Correlation Params:**
 - Model library RNG combinations: Default
 - Correlation: Linear Correlation
 - Correlation Matrix: =GBM_HW2F_correlation.cor_matrix

Correlation Matrix Preview

		Equity_ESG				Interest_Rate_ESG		
		corr_whitenoise[0] (Normal)	corr_whitenoise[1] (Normal)	corr_whitenoise[2] (Normal)	corr_whitenoise[3] (Normal)	corr_whitenoise[4] (Normal)	corr_vn[0] (Normal)	corr_vn[1] (Normal)
EquityESG	corr_whitenoise[0] (Normal)	1	0.822	0.681	0.971	0.733	0	0
	corr_whitenoise[1] (Normal)	0.822	1	0.686	0.806	0.66	0	0
	corr_whitenoise[2] (Normal)	0.681	0.686	1	0.651	0.904	0	0
	corr_whitenoise[3] (Normal)	0.971	0.806	0.651	1	0.68	0	0
	corr_whitenoise[4] (Normal)	0.733	0.66	0.904	0.68	1	0	0
InterestRate_ESG	corr_vn[0] (Normal)	0	0	0	0	0	1	0
	corr_vn[1] (Normal)	0	0	0	0	0	0	1

PathWise Modeling Studio

- Import and configure Model Libraries (e.g. pre-built Economic Scenario Generators)

The screenshot displays the PathWise Modeling Studio interface. The main window shows a data table with columns for time (dt_in_years), correlation (corr_whitenoise), and log returns. A dropdown menu for 'RNG Configuration' is open, listing options: chisquare, ncchisquare, normal, poisson, and uniform. The left sidebar shows a project browser with a tree structure including 'Model - GMMB', 'Data sources', 'custom_scenarios', 'market_data', 'shocks', 'Shocks', 'RNG Configuration', 'Model Libraries', 'Equity_ESG', 'Geometric_Brownian_Motio', 'Inputs', 'Calculations', 'simu_params', 'scenarios', 'Outputs', 'User-defined functions', 'Interest_Rate_ESG', 'Volatility_ESG', 'Calculations', 'Calculation Results', 'Greeks', 'Local Runs', and 'User-defined functions'.

dt_in_years	corr_whitenoise[0]	corr_whitenoise[1]	corr_whitenoise[2]	corr_whitenoise[3]	corr_whitenoise[4]	log_returns[0]	log_returns[1]	log_returns[2]	log_returns[3]
0	0.06301	0	0	0	0	0.0000	0.0000	0.0000	0.0000
1	0.08219	-0.1548973	-0.8779107	0.3820293	-0.4845392	-0.8619	-1.3759	-4.4918	1.8338
2	0.08219	0.04265733	0.423768	0.2174918	-0.4224617	0.1559	4.4716	2.3411	1.1584
3	0.08219	-1.006912	0.4300877	-1.285436	0.2424345	-5.8794	-12.7533	2.3601	-7.4764
4	0.08219	-1.465682	0.3621927	-1.367405	-0.4851904	-8.5016	-1.7838	1.9791	-7.9381
5	0.08219	-0.09411632	-0.7684383	-1.156138	0.08611837	-0.6681	-4.5345	-6.7575	0.3653
6	0.08219	-0.7466307	0.1432575	0.1404346	-0.7820051	-4.4784	0.6241	0.6079	-4.6812
7	0.08219	-0.4416853	1.038652	0.3633792	-0.3015822	-2.6899	5.7981	1.9262	-1.8866
8	0.08219	-1.062231	-0.06021303	-0.7155739	-0.7718784	-6.1989	-0.4535	-4.2113	-4.5341
9	0.08219	-0.8860358	0.3283949	0.493393	-0.672089	-5.2046	1.7588	2.7048	-3.9778
10	0.08219	1.374672	1.129136	0.8991433	1.117549	7.7378	6.3300	5.0112	5.5231
11	0.08219	0.1007481	0.6669464	0.3477014	0.5162982	0.4677	3.7142	1.8837	2.8504
12	0.08219	1.954194	1.634924	0.8792632	1.634747	11.1139	9.2833	4.9505	9.2823
13	0.08219	0.11927	-0.7092768	-0.5051804	0.02469391	0.5843	-4.1665	-2.9962	0.0420
14	0.08219	0.3938667	0.4305502	0.2574111	0.8597993	2.2269	2.4372	1.4445	4.8985
15	0.08219	-0.7380639	-1.767081	-0.6726584	-0.7953085	-4.2573	-10.1575	-3.8823	-4.5856
16	0.08219	-0.4155868	-1.023391	-0.3492023	-0.382019	-2.4471	-5.9322	-2.0665	-2.2547
17	0.08219	0.7107771	0.03922832	0.3088462	0.6509885	4.0496	0.1990	1.7450	3.7068
18	0.08219	0.1147579	0.2721997	0.5815271	0.3309397	0.6790	1.5817	3.3554	1.9185
19	0.08219	1.885169	2.216563	1.807503	1.778597	10.8843	12.7845	10.4390	10.2733
20	0.08219	-0.8022885	-1.668396	-0.7146163	-0.7122384	-4.5617	-9.5278	-4.0590	-4.0454
21	0.08219	1.615635	1.41437	1.582458	1.454906	9.2173	8.0633	9.0271	8.2957
22	0.08219	0.1332374	-0.1539606	0.1047874	0.1320681	0.7687	-0.8781	0.6056	0.7620
23	0.08219	2.005604	0.9153425	-0.01529968	2.061847	11.5071	5.2558	-0.0804	11.8296
24	0.08219	-0.5012379	0.1087353	0.09050599	-1.097984	-2.9234	0.5741	0.4696	-6.3450
25	0.08219	-0.9138255	-1.407303	-0.3786871	-1.010633	-5.2820	-8.1115	-2.2136	-5.8371

PathWise Modeling Studio

- Calculate number of time-steps to simulate

The screenshot displays the PathWise Modeling Studio interface. The main window shows a table with columns for projection dates and time steps. The 'Time' column is highlighted with a red circle, and a red arrow points to the 'Time' label. The table data is as follows:

	prev_projection_date	current_projection_date	next_projection_date	prev_projection_date_jd	current_projection_date_jd	projection_time_in_days	projection_time_in_y
0	2012-01-01	2012-01-01	2012-01-24	2455928	2455928	0	0.00000
1	2012-01-01	2012-01-24	2012-02-23	2455928	2455951	23	0.06301
2	2012-01-24	2012-02-23	2012-03-24	2455951	2455981	53	0.14521
3	2012-02-23	2012-03-24	2012-04-23	2455981	2456011	83	0.22740
4	2012-03-24	2012-04-23	2012-05-23	2456011	2456041	113	0.30959
5	2012-04-23	2012-05-23	2012-06-22	2456041	2456071	143	0.39178
6	2012-05-23	2012-06-22	2012-07-22	2456071	2456101	173	0.47397
7	2012-06-22	2012-07-22	2012-08-21	2456101	2456131	203	0.55616
8	2012-07-22	2012-08-21	2012-09-20	2456131	2456161	233	0.63836
9	2012-08-21	2012-09-20	2012-10-20	2456161	2456191	263	0.72055
10	2012-09-20	2012-10-20	2012-11-19	2456191	2456221	293	0.80274
11	2012-10-20	2012-11-19	2012-12-19	2456221	2456251	323	0.88493
12	2012-11-19	2012-12-19	2013-01-18	2456251	2456281	353	0.96712
13	2012-12-19	2013-01-18	2013-02-17	2456281	2456311	383	1.04932
14	2013-01-18	2013-02-17	2013-03-19	2456311	2456341	413	1.13151
15	2013-02-17	2013-03-19	2013-04-18	2456341	2456371	443	1.21370
16	2013-03-19	2013-04-18	2013-05-18	2456371	2456401	473	1.29589
17	2013-04-18	2013-05-18	2013-06-17	2456401	2456431	503	1.37808
18	2013-05-18	2013-06-17	2013-07-17	2456431	2456461	533	1.46027
19	2013-06-17	2013-07-17	2013-08-16	2456461	2456491	563	1.54246
20	2013-07-17	2013-08-16	2013-09-15	2456491	2456521	593	1.62466
21	2013-08-16	2013-09-15	2013-10-15	2456521	2456551	623	1.70685
22	2013-09-15	2013-10-15	2013-11-14	2456551	2456581	653	1.78904
23	2013-10-15	2013-11-14	2013-12-14	2456581	2456611	683	1.87123
24	2013-11-14	2013-12-14	2014-01-13	2456611	2456641	713	1.95343
25	2013-12-14	2014-01-13	2014-02-12	2456641	2456671	743	2.03562

PathWise Modeling Studio

- Define simulation columns and formulas

The screenshot displays the PathWise Modeling Studio interface. The main window shows a spreadsheet with columns for simulation results. A formula editor is open, showing a conditional formula for 'guaranteed_value'.

Formula Editor:

```

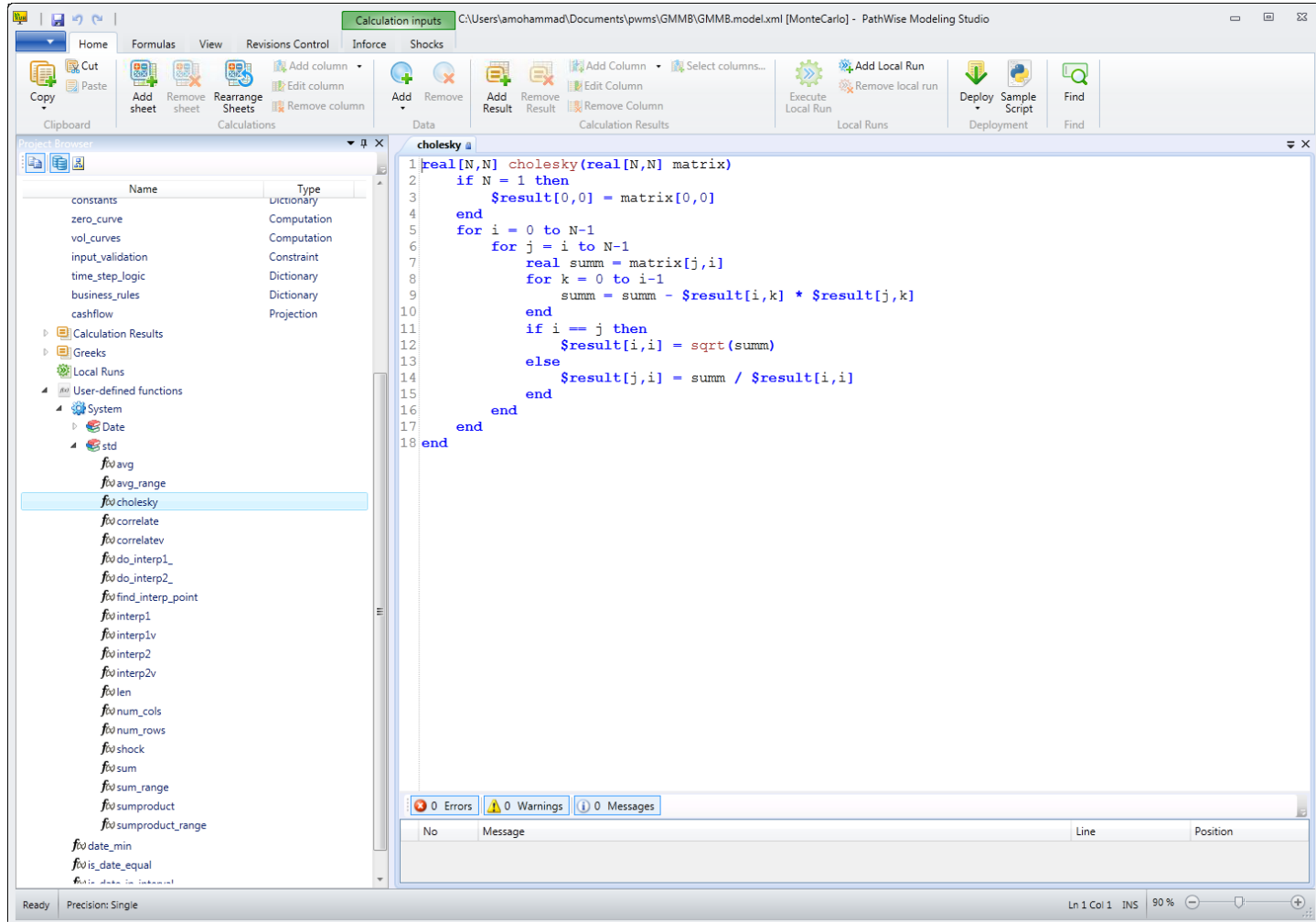
if is_ratchet_step then
  gv = max(total_account_value, prev(guaranteed_value))
else
  gv = prev(guaranteed_value)
endif
return gv
  
```

Spreadsheet Data (Columns 1-12):

	_return[2]	account_value[2]	log_r		_return[4]	account_value[4]	total_account_value	guaranteed_value	itm_pct	base_la
1	0.00%	\$00.00	0.00		000%	\$00.00	\$100,000.00	\$100,000.00	0.00%	0.00%
122	1.92%	\$00.00	1.83		517%	\$00.00	\$99,141.83	\$100,000.00	0.70%	1.00%
	2.41%	\$00.00	1.15		511%	\$00.00	\$99,296.53	\$100,000.00	0.70%	1.00%
	3.50%	\$00.00	-7.47		284%	\$00.00	\$93,626.80	\$100,000.00	6.37%	1.00%
	4.79%	\$00.00	-7.95		880%	\$00.00	\$85,995.97	\$100,000.00	14.00%	1.00%
	5.75%	\$00.00	0.36		551%	\$00.00	\$85,423.35	\$100,000.00	14.58%	1.00%
	6.38%	\$00.00	-4.68		208%	\$00.00	\$81,682.17	\$100,000.00	18.32%	1.00%
	7.26%	\$00.00	-1.88		328%	\$00.00	\$79,514.26	\$100,000.00	20.49%	1.00%
	8.11%	\$00.00	-4.57%	\$00.00	-5.04%	\$00.00	\$74,734.88	\$100,000.00	25.27%	1.00%
	9.05%	\$00.00	-3.97%	\$00.00	0.08%	\$00.00	\$70,944.74	\$100,000.00	29.06%	1.00%
	10.11%	\$00.00	5.52%	\$00.00	6.26%	\$00.00	\$76,652.30	\$100,000.00	23.35%	1.00%
	11.34%	\$00.00	2.85%	\$00.00	-2.65%	\$00.00	\$77,011.66	\$100,000.00	22.99%	1.00%
	12.50%	\$00.00	9.28%	\$00.00	5.56%	\$00.00	\$86,064.43	\$100,000.00	13.94%	1.00%
	13.96%	\$00.00	0.04%	\$00.00	-0.15%	\$00.00	\$86,568.73	\$100,000.00	13.43%	2.00%
	14.44%	\$00.00	4.89%	\$00.00	2.35%	\$00.00	\$88,518.16	\$100,000.00	11.48%	2.00%
	15.82%	\$00.00	-4.58%	\$00.00	-3.45%	\$00.00	\$84,828.74	\$100,000.00	15.17%	2.00%
	16.66%	\$00.00	-2.25%	\$00.00	-0.38%	\$00.00	\$82,778.07	\$100,000.00	17.22%	2.00%
	17.45%	\$00.00	3.70%	\$00.00	0.95%	\$00.00	\$86,199.04	\$100,000.00	13.80%	2.00%
	18.55%	\$00.00	1.91%	\$00.00	1.45%	\$00.00	\$86,786.30	\$100,000.00	13.21%	2.00%
	19.43%	\$00.00	10.27%	\$00.00	13.51%	\$00.00	\$96,765.66	\$100,000.00	3.23%	2.00%
	20.59%	\$00.00	-4.04%	\$00.00	-7.23%	\$00.00	\$92,450.63	\$100,000.00	7.55%	2.00%
	21.27%	\$00.00	8.29%	\$00.00	7.58%	\$00.00	\$101,377.10	\$100,000.00	-1.38%	2.00%
	22.06%	\$00.00	0.76%	\$00.00	0.02%	\$00.00	\$102,159.40	\$100,000.00	-2.16%	2.00%
	23.80%	\$00.00	11.83%	\$00.00	3.03%	\$00.00	\$114,618.10	\$100,000.00	-14.62%	2.00%
	24.70%	\$00.00	-6.34%	\$00.00	3.83%	\$00.00	\$111,315.90	\$100,000.00	-11.32%	2.00%
	25.14%	\$00.00	-5.83%	\$00.00	-2.90%	\$00.00	\$105,588.80	\$100,000.00	-5.59%	3.00%

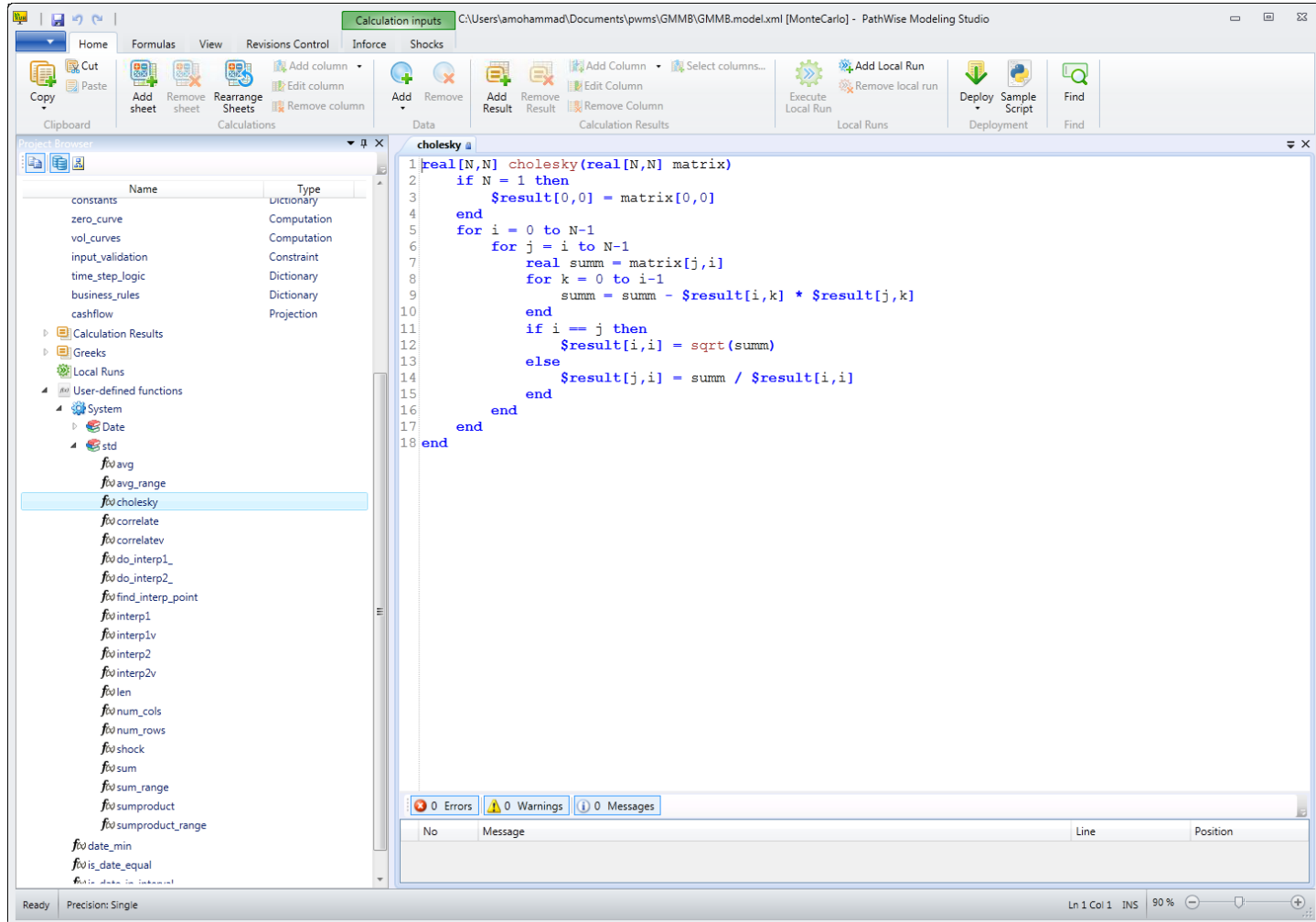
PathWise Modeling Studio

- Encapsulate re-usable logic in UDFs and UDF libraries



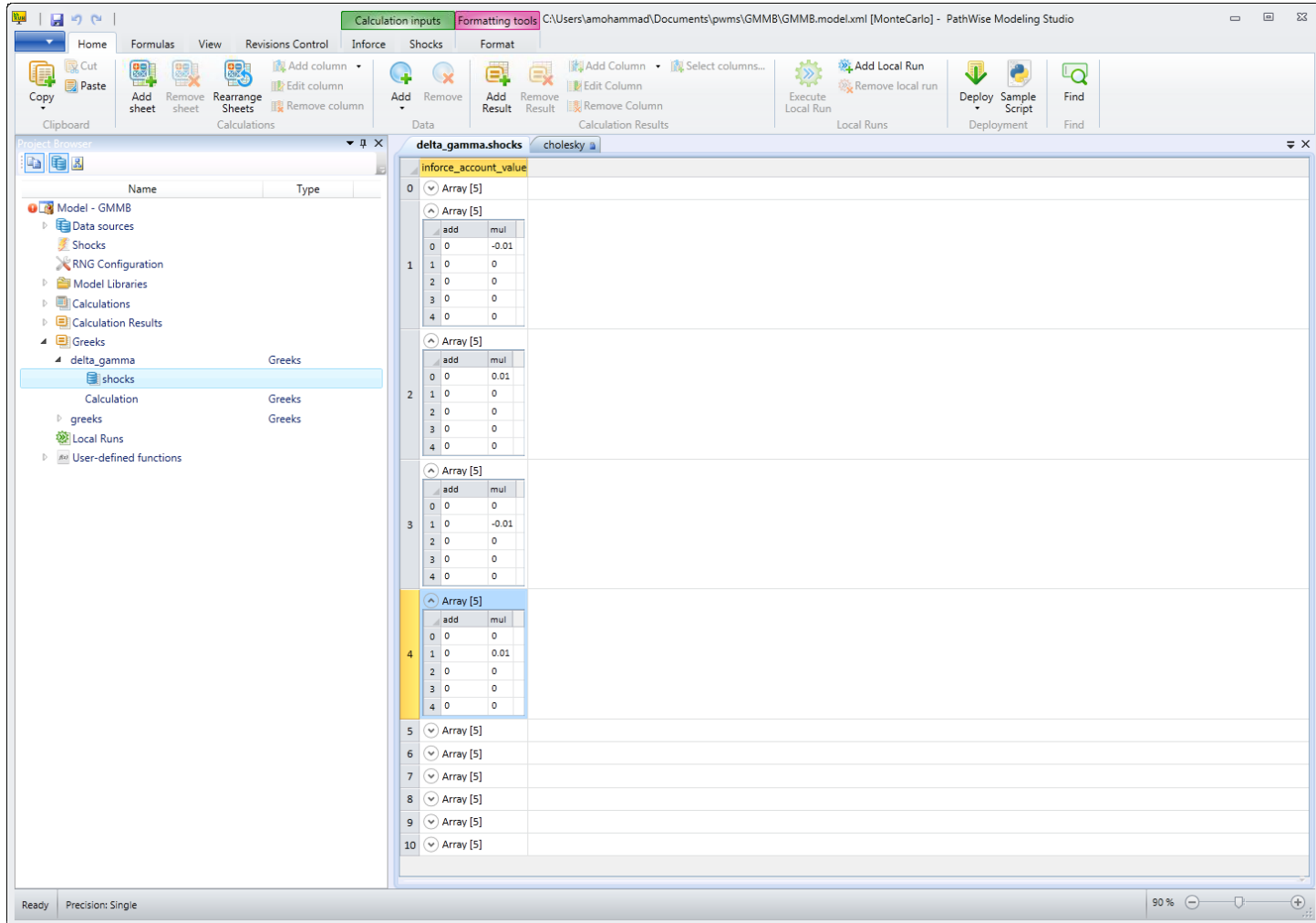
PathWise Modeling Studio

- Encapsulate re-usable logic in UDFs and UDF libraries



PathWise Modeling Studio

- Define model outputs (e.g. Greeks)



PathWise Modeling Studio

- Define model outputs (e.g. Greeks)

The screenshot displays the PathWise Modeling Studio interface. The main window shows a calculation named 'delta_gamma.Calculation' with a formula editor and a results table. The formula editor contains the following code:

```

idx_dn = $index*2 + 1
idx_up = $index*2 + 2
fmv_up = fmv[idx_up].avg_fmv
fmv_dn = fmv[idx_dn].avg_fmv
av_up = shock( inforce.account_value[$index], shocks[idx_up].inforce_account_value[$index] )
av_dn = shock( inforce.account_value[$index], shocks[idx_dn].inforce_account_value[$index] )
return ( fmv_up - fmv_dn ) / ( av_up - av_dn )

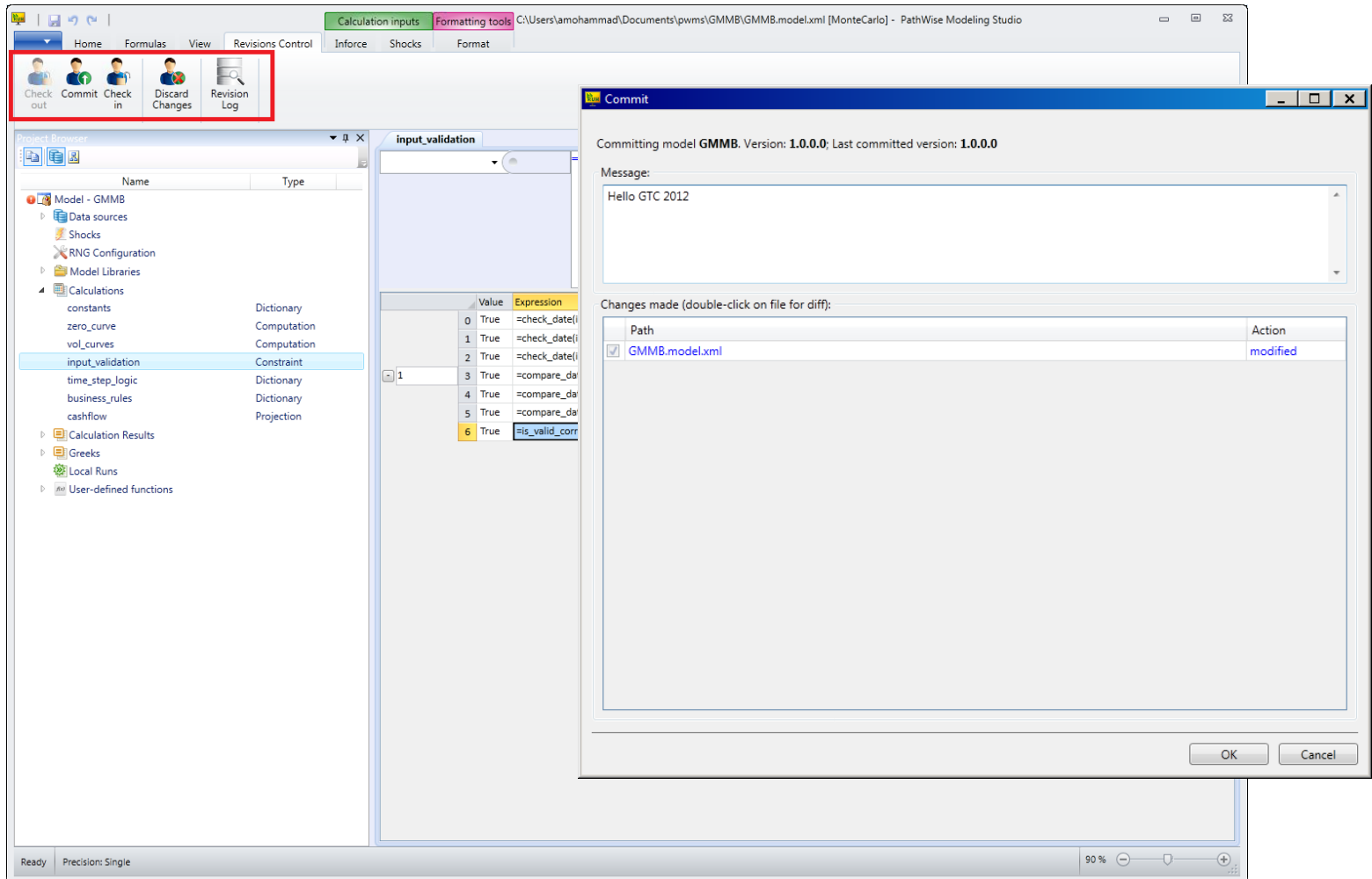
```

The results table shows the calculated values for various Greeks:

Name	Formula	Calculated Value
base_fmv	=fmv[0].avg_fmv	-72.0284
delta[0]	idx_dn = \$index*2 + 1 idx_up = \$index*2 + 2 fmv_up = fmv[idx_up].avg_fmv fmv_dn = fmv[idx_dn].avg_fmv av_up = shock(inforce.account_value[\$index], shocks[idx_up].inforce_account_value[\$index]) av_dn = shock(inforce.account_value[\$index], shocks[idx_dn].inforce_account_value[\$index]) return (fmv_up - fmv_dn) / (av_up - av_dn)	0.00425906
dollar_delta[0]	idx_dn = \$index*2 + 1 idx_up = \$index*2 + 2 fmv_up = fmv[idx_up].avg_fmv fmv_dn = fmv[idx_dn].avg_fmv av_up = shock(inforce.account_value[\$index], shocks[idx_up].inforce_account_value[\$index]) av_dn = shock(inforce.account_value[\$index], shocks[idx_dn].inforce_account_value[\$index]) av_base = inforce.account_value[\$index] return (fmv_up - fmv_dn) / (av_up - av_dn) * av_base	425.906
gamma[0]	idx_dn = \$index*2 + 1 idx_up = \$index*2 + 2 fmv_up = fmv[idx_up].avg_fmv fmv_dn = fmv[idx_dn].avg_fmv fmv_base = fmv[0].avg_fmv av_up = shock(inforce.account_value[\$index], shocks[idx_up].inforce_account_value[\$index]) av_dn = shock(inforce.account_value[\$index], shocks[idx_dn].inforce_account_value[\$index]) return (fmv_up - 2*fmv_base + fmv_dn) / ((av_up - av_dn)^2)	-2.408791E-08
dollar_gamma[0]	idx_dn = \$index*2 + 1 idx_up = \$index*2 + 2 fmv_up = fmv[idx_up].avg_fmv fmv_dn = fmv[idx_dn].avg_fmv fmv_base = fmv[0].avg_fmv av_up = shock(inforce.account_value[\$index], shocks[idx_up].inforce_account_value[\$index]) av_dn = shock(inforce.account_value[\$index], shocks[idx_dn].inforce_account_value[\$index]) av_base = inforce.account_value[\$index] return (fmv_up - 2*fmv_base + fmv_dn) / ((av_up - av_dn)^2) * av_base^2	-240.879

PathWise Modeling Studio

- Commit model to SVN source code repo



PathWise Modeling Studio

■ Compile and deploy model to GPUs

The screenshot displays the PathWise Modeling Studio interface. The ribbon at the top includes tabs for 'Calculation inputs', 'Formatting tools', 'Data', and 'Format'. The 'Deploy' button, represented by a green downward arrow, is circled in red. A 'Deploying...' dialog box is open, showing a list of messages:

- Info: C++ Project generation started for model 'GMMB'
- Warning: ..Column: 'hw2_parameters_hw2_drift' not used - removed
- Info: Generating c++ gpud interface
- Info: Generating python interface
- Info: Uploading model C++ sources to Linux Build Computer
- Info: Compiling model C++ sources
- Info: Uploading compiled model to /C:/Users/amohammad/AppData/Local/Temp/5/pwms_temp/GMMB_v1_0_0/work_temp
- Info: Calculating C:\Users\amohammad\AppData\Local\Temp\5\pwms_temp\GMMB_v1_0_0\work_temp\GMMB_v1_0_0.model:
- Info: Uploading Python interfaces for PwaStudio
- Info: Uploading py to \\AMZXA01.asgpn.net\DataProd#asg_600\PwasGridDeploymentRegistry\ (overwriting existing files)
- Info: Restarting grid. Please wait...
- Info: Requesting disconnect of 2 worker(s)
- Info: Waiting up to 60 seconds for workers to come back online
- Info: Grid restarted
- Info: Deployment completed

The dialog box also features a 'Debug Mode' checkbox, an 'Edit Deployment Configuration' button, a 'Copy to Clipboard' button, and a 'Close' button. The main window shows a spreadsheet with columns for 'total_account_val' and 'fwd_rate'. The status bar at the bottom indicates 'Ready' and 'Precision: Single'.

PathWise Modeling Studio

- Add GPU grid workers from the **Cloud**

The screenshot displays the PathWise Grid Management Console interface. At the top, there are tabs for 'session', 'workers (2/6)', 'models (4)', 'amazon workers', and 'settings'. Below the tabs, there is a 'Select All' checkbox and two buttons: 'Start new instances' and 'Terminate selected instances'. A table lists worker details:

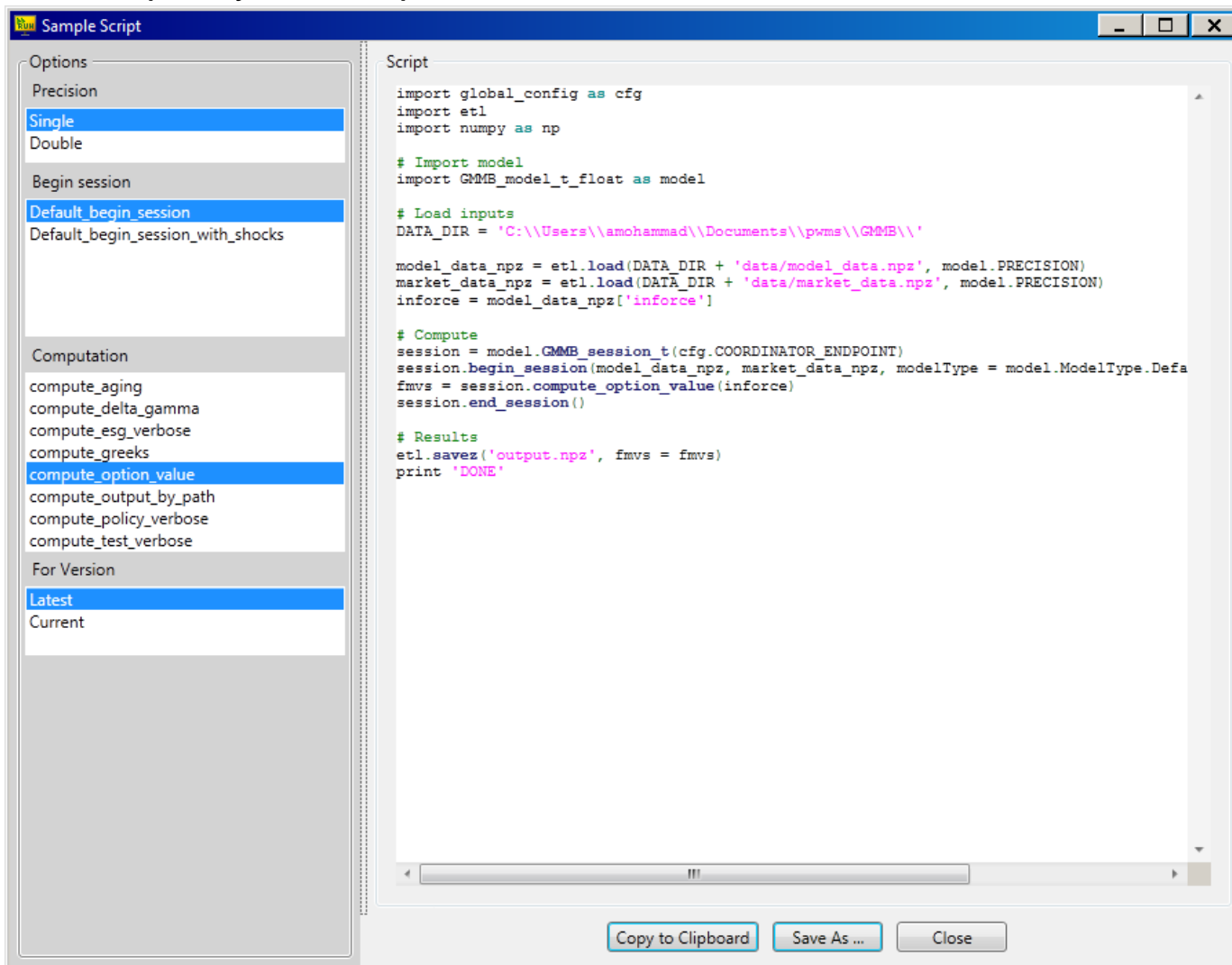
ip address	state	launch time	time running	termination policy	instance type	max price	started by
10.16.0.205	Online	5/10/2012 10:55:40 AM	09h 42m 46s	Never	Spot	\$1.500	ASGPW\svcpawise

A 'Start Instances' dialog box is open, showing options for 'Termination policy' (Never or After 1 idle hour), 'On-Demand instances', and 'Spot instances'. The 'Spot instances' section shows a 'Current price: \$0.665', a 'Max Price' input field with '0.665', and a 'Spot instances count' input field with '1'. A 'Start Spot instances' button is at the bottom of the dialog.

At the bottom of the console, it shows 'Current spot price: \$0.665' and a status bar with '10.17.163.175:6147' and 'last update : 20:38:32'.

PathWise Modeling Studio

- Generate sample Python script



PathWise Analytics Studio

- Run Python scripts from **PathWise Analytics Studio** (customized Python IDE)

The screenshot displays the PathWise Analytics Studio 2.0 interface. On the left, a Python script editor shows code for loading data, creating shock arrays, and computing P&L attribution. The right side features a task manager with progress bars for 'Compute Greeks' and 'Compute FMV'. Below the task manager is a console window and a 3D bar chart titled 'P&L Attribution, 2nd Order Greeks'. The chart shows P&L values for various market movements (MM, DEX, TSX, SPX, EAFE) and index shocks (Index Shock, Index Shock).

```
1 ## Copyright (C) Aon Benfield Securities 2012, All Rights Reserved
2 from settings import *
3
4 # Load data (inforce, assumptions, market)
5 mapped_inforce_npz = etl.load(DATA_DIR+'signed_mapped_inforce-20120222.npz',precision)
6 inforce = scale_inforce( mapped_inforce_npz, 20000, 41632 )
7 assumptions_npz = demo.get_best_assumptions( mapped_inforce_npz )
8 market_data = mapped_inforce_npz['market_data']
9
10 # Create shock array
11 n = 5
12 multiplier_shock = np.array([ 0.01, 0.01, 0.01, 0.01, 0.01 ])
13 num_shocks = 2 * n * n + 1
14 shocks = np.zeros( num_shocks, dtype=demo_model.shock_data_t )
15 shocks['av']['mul'] = shk.createShockArray( multiplier_shock )
16
17 # Compute Delta & Gamma
18 fmv = computeFMV( assumptions_npz, market_data, shocks, inforce, 'Compute Greeks' )
19 (jacobian, hessian) = shk.taylor_expansion( multiplier_shock, fmv )
20
21 # Compute FMV under market movement
22 newshocks = np.zeros( 2, dtype = demo_model.shock_data_t )
23 dx = np.array([[ 0.007, 0.005, -0.005, 0.01, 0.008 ]])
24 newshocks['av']['mul'][1,:] = dx
25 marketfmv = computeFMV( assumptions_npz, market_data, newshocks, inforce, 'Compute FMV' )
26
27 # Compare actual PnL versus approximated PnL
28 actual_pnl = marketfmv[1] - marketfmv[0]
29 full_2ndorder_pnl = (np.dot(jacobian,np.transpose(dx)) + \
30 0.5 * np.dot(dx,np.dot(hessian,np.transpose(dx)))) [0][0]
31 part_2ndorder_pnl = (np.dot(jacobian,np.transpose(dx)) + \
32 0.5 * np.dot( dx*dx, np.diag(hessian) )) [0][0]
33
34 # Plot PnL
35 data = 0.5 * ( np.transpose(dx) * hessian ) * dx
36 createplot( data )
```

Task manager progress:

- Compute Greeks: 00:04:03, 100%, 1020000/1020000
- Compute FMV: 00:01:15, 100%, 40000/40000

Figure 1: P&L Attribution, 2nd Order Greeks

3D Bar Chart Data (Approximate):

Category	P&L Value
MM	~10000
DEX	~10000
TSX	~10000
SPX	~10000
EAFE	~10000
Index Shock	~10000

PathWise Analytics Studio

- Run Python scripts from **PathWise Analytics Studio** (customized Python IDE)

The screenshot displays the PathWise Analytics Studio 2.0 interface. The main window is titled "PathWise Analytics Studio 2.0" and contains a Python script editor on the left, a task manager on the right, and a console window at the bottom right. The script editor shows a Python script with the following code:

```
3 import numpy as np
4 import utils
5
6 # import model
7 import GMM
8 import GMM
9
10 NUM_INDICES
11
12 # Load input
13 DATA_DIR =
14
15 model_data
16 market_data
17 shocks_npz
18 inforce = n
19
20 # modify in
21 inforce['nu
22
23 inforce['ts
24 inforce['ts
25
26 inforce['ac
27 inforce['gl
28 inforce['ra
29
30 # create sh
31 num_shocks
32 min_av_shoc
33 max_av_shoc
34 shock_grid
35
36 shocks_npz
```

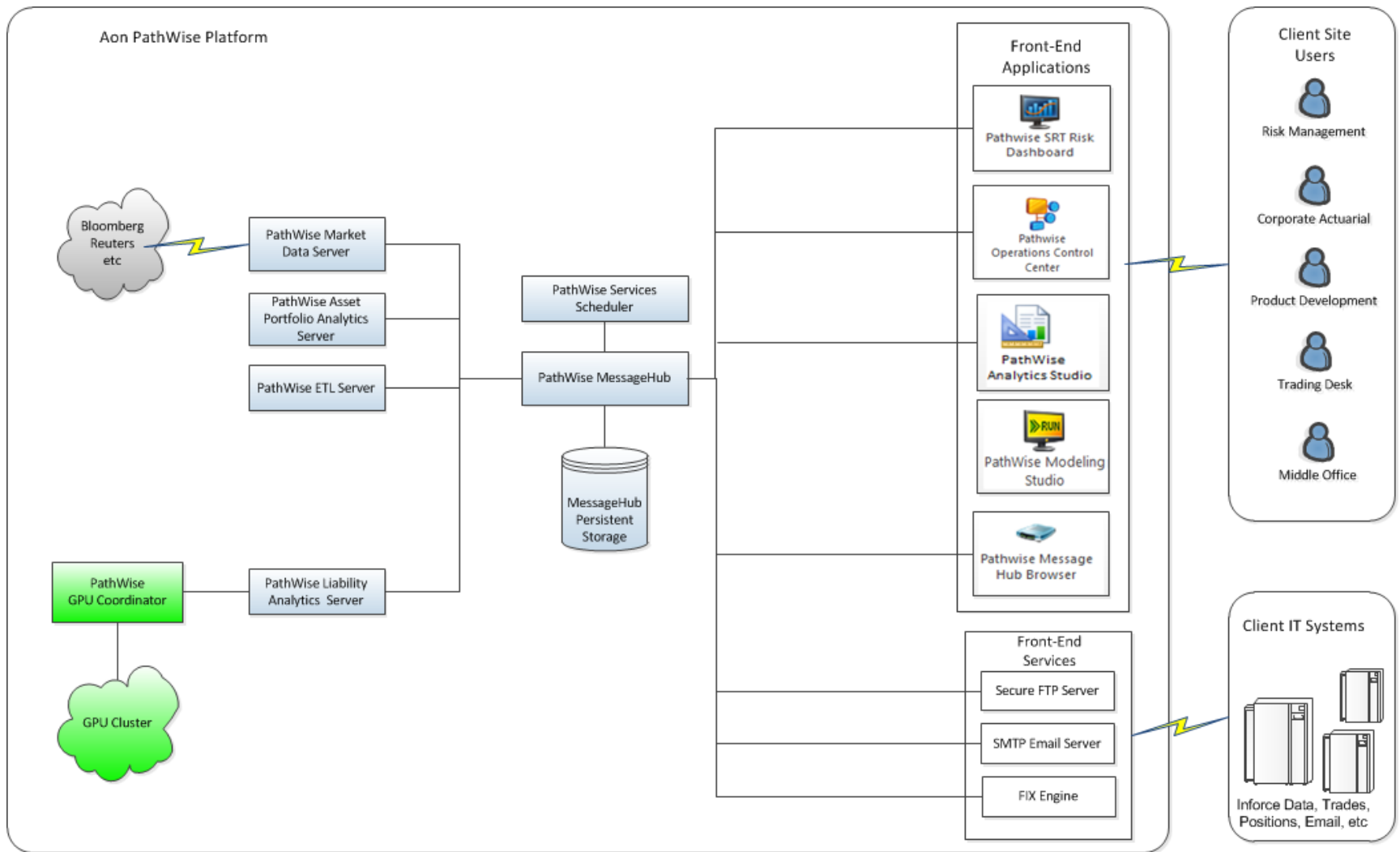
The task manager window shows two tasks: "GMMB_session_t.compute_delta_gamma" with a progress bar at 100% and a status of "1/1". The console window shows the output of the script:

```
NUM_WORKERS: 10
>>> print 'Hello GTC 2012'
Hello GTC 2012
>>>
```

The console window also shows the execution time: "00:04:10". The status bar at the bottom indicates "Line: 16 Column: 90".

The figure window, titled "Figure1", displays two plots. The top plot, "Delta Sensitivity", shows Delta (Y-axis, 0.00 to 0.30) versus Account Value Shock (%) (X-axis, -60 to 60). The bottom plot, "Gamma Sensitivity", shows Gamma (Y-axis, -0.0000014 to 0.0000000) versus Account Value Shock (%) (X-axis, -60 to 60).

PathWise Platform



PathWise MessageHub

Pathwise MessageHub Browser

Topics

- Summary
- By Topic
 - audit
 - days
 - market
 - bloomberg_eod_quotes**
 - bloomberg_eod_reference_data
 - market_aux_data
 - liability_shocks
 - dV01_risk_factor_changes
 - index_total_returns
 - liability_input_data
 - signed
 - signed_assumptions
 - signed_market_data
 - signed_bifurcation_cohorts
 - signed_excluded_contracts
 - signed_risk_limit_params
 - signed_rw_params
 - signed_rw_params_mccsr
 - signed_unitrax_extract
 - signed_nav
 - signed_positions_file_list
 - signed_positions
 - signed_mapped_inforce_file_list
 - signed_mapped_inforce
 - signed_liability_greeks
 - signed_mapped_inforce_control_report
 - signed_asset_greeks
 - real_world_scenarios
 - etl
 - nav
 - trades
 - positions
 - inforce
 - control_reports
 - pas_reports
 - eod_jobs_control
 - srt
 - logs
 - config
 - rerun
 - diy_run

Topic	Time	Seq No	Key
bloomberg_eod_quotes	1/23/2012 12:00:00 AM	7171874	file:#2012\#201201\#20120123\market\bloomberg_eod_quotes-20120123-000000-0049PUQ-0D.npz
bloomberg_eod_quotes	1/20/2012 12:00:00 AM	7123794	file:#2012\#201201\#20120120\market\bloomberg_eod_quotes-20120120-000000-0048OR6#00-0D.npz
bloomberg_eod_quotes	1/20/2012 12:00:00 AM	7123777	file:#2012\#201201\#20120120\market\bloomberg_eod_quotes-20120120-000000-0048OQP-0D.npz
bloomberg_eod_quotes	1/19/2012 12:00:00 AM	7079360	file:#2012\#201201\#20120119\market\bloomberg_eod_quotes-20120119-000000-0047QGW#00-0D.npz
bloomberg_eod_quotes	1/19/2012 12:00:00 AM	7079343	file:#2012\#201201\#20120119\market\bloomberg_eod_quotes-20120119-000000-0047QGF-0D.npz
bloomberg_eod_quotes	1/18/2012 12:00:00 AM	7015906	file:#2012\#201201\#20120118\market\bloomberg_eod_quotes-20120118-000000-0046DIA#00-0D.npz
bloomberg_eod_quotes	1/18/2012 12:00:00 AM	7015889	file:#2012\#201201\#20120118\market\bloomberg_eod_quotes-20120118-000000-0046DHT-0D.npz
bloomberg_eod_quotes	1/17/2012 12:00:00 AM	6947129	file:#2012\#201201\#20120117\market\bloomberg_eod_quotes-20120117-000000-0044WFT#00-0D.npz
bloomberg_eod_quotes	1/17/2012 12:00:00 AM	6947112	file:#2012\#201201\#20120117\market\bloomberg_eod_quotes-20120117-000000-0044WFC-0D.npz
bloomberg_eod_quotes	1/16/2012 12:00:00 AM	6878439	file:#2012\#201201\#20120116\market\bloomberg_eod_quotes-20120116-000000-0043FFR#00-0D.npz
bloomberg_eod_quotes	1/16/2012 12:00:00 AM	6878422	file:#2012\#201201\#20120116\market\bloomberg_eod_quotes-20120116-000000-0043FFA-0D.npz
bloomberg_eod_quotes	1/13/2012 12:00:00 AM	6846508	file:#2012\#201201\#20120113\market\bloomberg_eod_quotes-20120113-000000-0042QSS#00-0D.npz
bloomberg_eod_quotes	1/13/2012 12:00:00 AM	6846491	file:#2012\#201201\#20120113\market\bloomberg_eod_quotes-20120113-000000-0042QSB-0D.npz
bloomberg_eod_quotes	1/12/2012 12:00:00 AM	6788223	file:#2012\#201201\#20120112\market\bloomberg_eod_quotes-20120112-000000-0041HTR#00-0D.npz
bloomberg_eod_quotes	1/12/2012 12:00:00 AM	6788206	file:#2012\#201201\#20120112\market\bloomberg_eod_quotes-20120112-000000-0041HTA-0D.npz
bloomberg_eod_quotes	1/11/2012 12:00:00 AM	6757137	file:#2012\#201201\#20120111\market\bloomberg_eod_quotes-20120111-000000-0040U9#00-0D.npz
bloomberg_eod_quotes	1/11/2012 12:00:00 AM	6757120	file:#2012\#201201\#20120111\market\bloomberg_eod_quotes-20120111-000000-0040TTS-0D.npz
bloomberg_eod_quotes	1/10/2012 12:00:00 AM	6727726	file:#2012\#201201\#20120110\market\bloomberg_eod_quotes-20120110-000000-004075A#00-0D.npz
bloomberg_eod_quotes	1/10/2012 12:00:00 AM	6727709	file:#2012\#201201\#20120110\market\bloomberg_eod_quotes-20120110-000000-004074T-0D.npz
bloomberg_eod_quotes	1/9/2012 12:00:00 AM	6686893	file:#2012\#201201\#20120109\market\bloomberg_eod_quotes-20120109-000000-0032BNI#00-0D.npz

nzp structure	Sys_Instrument	Sys_HistoryDate.year	Sys_HistoryDate.month	Sys_HistoryDate.day	PX_LAST	PX_ASK	PX_BID	PX_SETTLE	CHG_PCT_1D
0	USDCAD Curncy	2012	1	12	1.0191	1.0192	1.019	NaN	-0.05
1	USDCAD Curncy	2012	1	13	1.0232	1.0235	1.0228	NaN	0.4
2	USDCAD Curncy	2012	1	16	1.0179	1.018	1.0177	NaN	-0.52
3	USDCAD Curncy	2012	1	17	1.0151	1.0152	1.015	NaN	-0.28
4	USDCAD FI600 Curncy	2012	1	12	1.0183	1.0183	1.0182	NaN	-0.1
5	USDCAD FI600 Curncy	2012	1	13	1.0226	1.0227	1.0226	NaN	0.42
6	USDCAD FI600 Curncy	2012	1	16	1.0179	1.018	1.0178	NaN	-0.46
7	USDCAD FI600 Curncy	2012	1	17	1.0152	1.0153	1.0152	NaN	-0.27

dtype description show as text

String[32]	Sys_Instrument
Struct	Sys_HistoryDate
Double	PX_LAST
Double	PX_ASK
Double	PX_BID
Double	PX_SETTLE
Double	CHG_PCT_1D

Message Hub is alive 20 topic keys

PathWise Operations Control Center

The screenshot displays the Pathwise Operations Control Center interface. The main window title is "Pathwise Operations Control Center". The current day is 2012-01-24 (working day) and the operating EOD date is 2012-01-23. The interface is divided into several sections:

- LIABILITY** (selected tab)
- ASSETS**
- PAS**
- SYSTEM**

The left sidebar shows a tree view of reports under "Operating Date (Monday, 2012-01-23)". The selected report is "LPAS1 - Liability FMV P&L".

Liability Performance Attribution Report 1: Liability FMV P&L

Info

	Previous EOD	Current EOD
Operating Date	2012-01-20	2012-01-23
Liability Fair Market Value (CAD)	-22,073,580.51	-19,291,043.71

Total Liability FMV P&L

	P&L	Currency
Liability FMV P&L Explained	2,796,790.77	CAD
Liability FMV P&L Unexplained	-14,253.97	CAD
Total Liability FMV P&L	2,782,536.80	CAD

Equity Risk Liability P&L

	MM	DEX	TSE	S&P500	EAFE	Total	Currency
Total Return (%)	0.01	-0.19	1.01	-0.52	0.48		
Previous EOD	30,130,062.63	147,168,724.1	196,330,423.6	33,085,371.82	20,531,311.23	427,245,893.4	CAD
Liability Delta		1		7		6	

PathWise Seriatim Real-Time Risk System



Conclusions

PathWise Modeling Studio Roadmap

- **Growing list of different Model Types**

- Monte Carlo Models (✓ available now)
- Data Parallel Models (✓ available now)
- Nested Stochastic Simulation Models (✓ in progress)
- Finite Difference Method PDE solvers
- Support for non-trivial interactions between CUDA threads and between GPU grid nodes

- **A large set of GPU Model Libraries**

- Economic Scenario Generators Library (✓ available now)
- Standard and Exotic Hedge Program Instrument Library (✓ available now)
- Hedge Strategy Library (✓ available now)
- International Capital and Reserve Library (✓ in progress)

- **Automatic Model Differentiation (Adjoint Method) (✓ in progress)**

- PWMS compiler can support automatic differentiation
- Allows computation of model sensitiveness (Greeks) without re-simulation

Conclusions

- **High Productivity Computing (HPC)**
 - End-user focused tools for computational scientists
 - User-friendly, high productivity environments
 - Easy access to high throughput computing infrastructure (e.g. GPU cloud)

- **HPC requires**
 - Domain Specific Languages, Middleware, User-Interfaces
 - Even entire Domain Specific *Platforms*
 - Domain knowledge experts to design and support such tools
 - Investment in software tools

- **HPC provides**
 - Unprecedented user productivity and computational power