High Performance Computing in the Financial Industry
Problems, Methods & Solutions

Erik Vynckier  Chief Investment Officer — Insurance EMEA
Agenda

- Big Data Tools for Algorithmic Investing
- Scenarios for Portfolio Construction
- Balance Sheet Simulation and Capital Modelling
- Liquidity Planning – Clearing and Collateral
- Discounting – Collateral Matters
- Regulatory Reporting – Monitoring Systemic Risk
- Conclusions
Investors Are Compensated for Systematic Risk Factors

- **Risk Sharing**: Compensation for bearing risks or insuring against risks
  - Traditional Beta
  - Specific Risk Events
  - Liquidity
  - Agency Motivations
  - Investor Constraints

- **Structural Constraints**: Compensation for having fewer investment constraints
  - Underreaction to Information
  - Overreaction to Information

- **Information Processing**: Compensation for processing information better
  - Equity Risk Premium
  - FX Carry
  - Liquidity
  - Commodity Carry
  - Low Beta
  - Momentum
  - Quality

Back-testing, fine-tuning and implementing quantitative and algorithmic investment strategies can benefit from Big Data Analytics.
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One-for-one porting of mathematical techniques from the physical sciences into investment practice has often produced catastrophic outcomes.
Capital Markets Engine Modelling the Economic Building Blocks of Return

- Global real-world scenarios
- Multiple horizons, multi-currency
- Economically underpinned
- Consistent across asset classes

Typically 10,000+ scenarios are needed for reliable outcomes such as converged prices and risk sensitivities and accurate measurement of tail risks

Equity

- Return on Equity
- Dividend to Book
- Price to Book

Profitability

- Book Growth = ROE – D/B
- Price Appreciation = Book Growth + Valuation Change
- Dividend Yield = D/B × B/P = D/B / P/B

- Credit
- Spreads
- Ratings

- Macroeconomy

- Sovereign Bonds

- Currency Exchange Rates

- Alternatives

- Return on Equity
- Profitability

Consistently underpinned and accurate.
Multitude of Scenarios Captures both Risks and Returns

Range of Compound Growth Rates over 10 Years (in Pounds)

View of the future by means of probabilities, not point forecasts

As of December 31, 2014
Returns hedged into GBP and reported in GBP
Data do not represent past performance and are not a promise of actual returns or range of future results.
Source: AB
Entrenched method for modelling financial risks and deriving metrics, such as option pricing, risk sensitivities and Value @ Risk
Dynamic Stochastic Programming: Optimizing across Scenarios

Glide Paths Optimise not Static Allocations but Dynamic Strategies

How should an investor allocate money to investments before and in retirement to increase wealth and consumption while reducing the risk of running out of savings?
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- Powerful Platforms
Applying Scenarios to Risk & Capital Management
Internal Models for Solvency II Capital Models of Insurance Firms

- **Exposures**
  - Market risks
  - Insurance risks
  - Stresses
  - Correlations

- **Internal model**
  - Scenario generator
  - High Performance Computation
  - Businesses and assets which are poorly covered by the standard model

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Accurate tail risk metrics require a massive number of scenarios!
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High Performance Computing in Finance

Regulatory Overview – A Global Picture

- **Solvency II**
  - Pillar 1: Valuation and risk-based capital requirements
  - Pillar 2: Governance and risk management requirements,
  - Pillar 3: Supervisory reporting and public disclosure.

- **Trade Reporting**: Completed
- **Mandatory clearing**: anticipated February-April 2016
- **Margining requirements**: phase in from Dec 2015 to Dec 2019

- **CRR / CRD IV**
  - OTC Derivatives capital costs: **Completed**

- **MiFID II / MiFIR**
  - Trade Reporting: **Completed**
  - Mandatory clearing: anticipated February-April 2016
  - Margining requirements: phase in from Dec 2015 to Dec 2019
  - Market structure, execution venues, trading transparency requirements: **anticipated January 2017**

- **Dodd-Frank Act Title VII**
  - Trade Reporting: **Completed**
  - Mandatory clearing: **Completed**
  - Mandatory Execution: **Completed**
  - Margining Requirements: **TBC**

- **Basel III**
  - Leverage constraint
  - NSFR
  - Capital requirement
  - LCR
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Many assets require derivatives overlays to match liabilities – but few assets provide eligible collateral or cash for clearing.
Basic Definitions for Counterparty Modelling

- **Expected Exposure** (EE) is the average counterparty exposure on a future date.

- **Expected Positive Exposure** (EPE) is the average exposure – over positive scenarios – on a future date (ignore negative scenarios).

- **Potential Future Exposure** (PFE) is the maximum expected positive exposure on a future date at some level of confidence.

- **Credit Valuation Adjustment** (CVA) is a fair-value adjustment to the price of a derivative taking into account counterparty credit risk = EPE x CDS x LGD

Multiple time-step, path-dependent simulations across the complete book of derivatives, collateral assets and counterparties over the entire life of the trades.
Yield Curve Evolution – Sample Scenario
Mark-to-Market of Entire Swap Portfolio for Each Scenario

Portfolio exposure across scenarios indicates potential liquidity sinks
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Best-in-Class Analytics
Discounting Example Accounting for Collateral Optionality

Market data:
- SONIA
- Fed Funds
- EONIA
- Cross currency basis swaps GBPUSD and EURUSD
- Spot GBPUSD and EURUSD
- GBP, USD, EUR Libor 3m
- GBP Libor 6m
- Term structures out to 60Y
Best-in-Class Analytics
Revaluation of GBP 4 billion under different Collateral Regimes

- GBP 4 billion notional in 400 fixed receiver swaps maturing over 2015-2039 – deeply in the money since traded in 2008
- Approximately GBP 800 million of mark-to-market – interest in re-couponing?
- Mix of bilateral collateral programs – accurate valuations and risk sensitivities matter in trading!

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<th>EONIA</th>
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- Variations of GBP 27 million depending on collateral policies
- Risk sensitivities of approximately GBP 5.3 million smeared out over different market parameters
- You require the same analytic capabilities as your brokers
EPE & CVA Estimations for a GBP 4 billion Receiver Swap Book

- Market Value of receiver swap book approximately GBP 800 million
- Counterparty Value Adjustment GBP 91 million
- Would be charged as approximately 20 bp adjustment on the quoted swap rate
- Real-time requirement for 30,000 scenarios
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Asset and Liability Reporting Templates for Solvency II Pillar 3

- **D1** - line-item reporting of assets held for insurer
- **D2** - derivatives (trades and open positions)
- **D3** - comprehensive insurer report (including bank deposits & self-occupied property)
- **D4** - look-through table (fund-of-funds) awaiting clarification on “materiality”
- **D5** - securities financing (securities lending and borrowing, repurchase agreements)
- **D6** - collateral (posted and received)
- **XBRL** format for Big Data reporting, searching and analysing

Supervision focusing on systemic effects now a real prospect
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Scope for Innovative Technology in Banking, Insurance and Investment

- Affordable computational platforms and accessible big data analytics are here & now

- A variety of sensible applications are easily identified!
  - Investment: information processing, portfolio construction, implementation, dynamic hedging, reporting …
  - Balance sheets: risk and capital management, liquidity planning, strategic planning

- Regulators ask for more risk reporting to enable systemic monitoring

- Do we have the right staff, the right organization, the optimal value chain?

  Are our organizations fit for harnessing technology?
A WORD ABOUT RISK

- Market Risk: The market values of the investments may rise and fall from day to day, so investments may lose value.

- Interest Rate Risk: Bonds may lose value if interest rates rise or fall—long-duration bonds tend to rise and fall more than short-duration bonds.

- Credit Risk: A bond’s credit rating reflects the issuer’s ability to make timely payments of interest or capital—the lower the rating, the higher the risk of default. If the issuer’s financial strength deteriorates, the issuer’s rating may be lowered and the bond’s value may decline.

- Allocation Risk: Allocating to different types of assets may have a large impact on returns if one of these asset classes significantly underperforms the others.

- Foreign Risk: Investing in overseas assets may be more volatile because of political, regulatory, market and economic uncertainties associated with them. These risks are magnified in assets of emerging or developing markets.

- Currency Risk: currency fluctuations may have a large impact on returns and the value of an investment may be negatively affected when translated into the currency in which the initial investment was made.

- Capitalization Size Risk (Small/Mid): Holdings in smaller companies are often more volatile than holdings in larger ones.

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Appendices

- High Performance Computing in Finance – the Issues
- Mathematical Finance Topics
Why High Performance Computing in Finance?

- Daunting numerical challenges in risk management
  - Value-at-Risk and coherent tail risk measures for complex businesses
  - Stress testing and preparedness for crisis with a living will
  - Regulators and politicians hammering firms to post satisfactory capital
  - Reporting requirements in short time-frames (Basel III, Solvency II)
  - Stochastic-on-stochastic “nested” Monte Carlo simulations – a computational bottleneck

- Financial product variety and complexity
  - Products with mix of financial and insurance features offering clients discretion
  - Hybrid or cross-asset exposure—equity, bonds, currencies, commodities

- Need for real-time pricing, risk, trade and positions metrics
  - High frequency trading
  - Dynamic hedging of guaranteed products
  - Counterparty modeling and real-time selection of counterparties

- Restructuring adds to demand in balance sheet and risk computing

Business accelerates: computational tools need to accommodate the change agenda
Why Now?

- High-performance computing is **no longer esoteric**:
  - **Moore’s “bet”**: a new chip design for a new foundry every two years
  - Limits in cooling and quantum effects at very small transistor sizes have halted progress
  - **Many** cores: NVIDIA (very many), Intel XeonPhi
  - New platforms — **use all of the silicon all off the time**: Altera, Xilinx
  - High performance computing is now established in many other sciences and technologies

- High performance computing has become **affordable**!

- Financial engineers are still betting on Moore’s law
  - Higher integrated circuit density and clock speed are not forthcoming
  - As of old we write “correct” code and expect the compiler to handle it

**Optimal mix of platform + algorithm + numerics + code new game in quant development**
What Are the Options?

- **Cheap** high performance computing has arrived!

- **Multi-core** lends itself well to embarrassingly parallel tasks
  - nVidia Tesla, Kepler, Maxwell…, Xeon Phi
  - OpenCL, OpenACC, OpenMP, CUDA
  - Bandwidth considerations on data movement & saturating the cores
  - Libraries (NAG, nVidia, MathWorks), domain specific languages (SciComp)

- **Reconfigurable gate arrays**
  - Verilog High Definition Language a daunting task for financial engineers
  - Standard and portable OpenCL for Xilinx FPGA
  - MaxCompiler with a high-level language for dataflow computing on FPGA
  - MATLAB VHDL toolkit

- **Grids are now called **clouds**
  - On-demand **bursting** to needed capacity fills punctual requirements
  - Outsourced, low capital cost at the risk of dependency on provider
  - Azure, amazon, peer one…outsourced service organizations operating under a Service Level Agreement
  - Hosting the data in the cloud
Platforms Come and Go … but Applications Remain

- When developing, do we know which platform we will run on?
  - Turn code into binary only when the target platform is identified: Java $\rightarrow$ intermediate language $\rightarrow$ virtual machine $\rightarrow$ bytes
  - How to manage data, libraries, … and output in this concept?
  - Compiler directives to the pre-processor to do the hard work?
  - Defer to libraries or domain specific languages to do the hard work?

- The software life-cycle
  - Rewrite? Re-factor? Port and Run?
  - Initially clean code base starts to diverge into platforms versions

- Application to very large codes and computational tasks (Basel III, Solvency II)?
- Ultimately I want infrastructure and software that follows and fits my business

Cost of ownership — static and dynamic — across versions of hard and soft
Appendices

- High Performance Computing in Finance – the Issues
- Mathematical Finance Topics
Simple Mathematics: How much is $1 paid tomorrow, worth today?

- Bootstrapping was considered straightforward, yet it is controversial
  - By far the most important procedure in finance — $$$ monetary impact in settling trades
  - Interpolation techniques matter — discrepancies frequent and large

- “Dual-curve” discounting of $/€/£ Libor products
  - Fed Funds, EONIA, SONIA money market collateral priced off basis swaps
  - Foreign currency collateral priced off cross-currency basis swaps
  - Corporate debt and other credit-risky collateral

- Cheapest-to-deliver discounting
  - Easy but wrong: cheapest to deliver on a forward basis
  - Accounting for the substitution rights on collateral path dependent

- Maintenance of existing trades
  - Recouponing in-the-money swaps
  - A third counterparty steps into in existing trade: novation
  - Trade compression, reducing triangular trades, meets 3 ISDA/CSA
  - Settlements in cash invariably controversial and adversarial in nature
Complicated Mathematics: Stochastic Calculus

- **Partial differential equations** with multiple risk factors for option value $V(S,t)$
  \[
  \frac{\partial V}{\partial t} + \frac{1}{2}\sigma^2 S^2 \frac{\partial^2 V}{\partial S^2} + rS \frac{\partial V}{\partial S} - rV = 0
  \]

- **Monte Carlo** simulations (equivalence derived from Feynman-Kac theorem)
  - Just too many risk factors … just too many product features … or you don’t know any better method
  - Random-number generators for chosen platform?
  - Variance reduction methods for chosen platform, importance sampling, structured quasi-random numbers
  - Least-squares Monte Carlo and replication portfolios

- **Discrete or Fast Fourier Transforms** for known characteristic functions of probability laws

- Even “analytical” solutions rest on transcendental functions — iteratively approximated

- Risk sensitivities — the so-called “Greeks” — useful for risk managing a book of derivatives, for hedging and for estimating bid-ask spreads

- **Calibration to market + valuation + Greeks + all strikes + all maturities + all pay-offs on the trading book + ability to implement stress tests** is the real benchmark for calling a valuation method “efficient”
Explicit and Hidden Markowitz in Portfolio Optimization

- Portfolio optimization trading off risks and returns
  - Capital Asset Pricing Model: Minimize $T(\text{weights}) \times \text{Covariance} \times \text{weights}$ subject to return constraint
    - Mythical investors investing according to mythical utility functions
    - “Arbitrage” of the past record or a flawed numerical treatment
  - Tricking the Covariance matrix
    - Time-weighting
    - Bayesian prior
      - You bet less aggressively on a flawed approach
      - You do not bet with better odds
      - Single horizon implies no time dimension, so no cash flows in or out, portfolio rebalancing
  - Robust prediction of expected returns is virtually impossible

- Variations on a theme by Markowitz: risk and returns relative to benchmark
  - Black-Litterman optimization
  - Run active alpha versus tracking error as a risk measure
  - Long-short optimization
2nd Wave of Portfolio Optimization: Dynamic Stochastic Programming

- Newer metrics and newer optimization techniques
  - **Risk parity** instead of market cap weighting
  - Identify, invest in and mix and match **risk premium from diverse risk factors**
  - Rely on the **central limit theorem** to reduce skew and kurtosis
  - **Entropy pooling** for optimization of asset allocation
  - **Time is of essence**: lifecycle savings and drawdown, dynamic strategies

- **Attribution** of risk, return, capital, liquidity …
  - Decompose aggregate metric into its **marginal contributions**
  - **Copulas** for aggregating risk factors **across risks and business lines** — admits **fat tails**

- Multiple time-steps as intermediate experience matters to the investor
  - Cash in- and out-flows need to reflected
  - Dynamic asset allocation, reflection trading opportunities and cost of illiquidity

**Dynamic stochastic programming is in my view the most promising approach**
Bumping to Compute Risk is Slow and Inaccurate

- Calibration of model to market data and valuation of financial contract

- **As well as**

- Greeks: perturbing parameter with a bump or are there better techniques?

- Entire trading book
  - All maturities
  - All tenors
  - All strikes
  - Plain vanilla (linear pay-offs) and exotics (more complicated pay-offs)

- Stress tests — should not be an afterthought of model and code development

**Plan the code to do the full job before hacking your first lines**
PDEs: Get your Greeks for Free!

- Ultimately linearization (often Finite Differences) and Gaussian elimination
  - Decompose into LU once, then column-band the matrix of PDE coefficients with all pay-offs, all strikes
  - Add columns with extra pay-offs as you back-solve — solve across all maturities in one go

- People don’t apply this economy because:
  - They don’t see through a layered, verbose object-oriented code
  - The object orientation doesn’t allow them to re-factor for it

- The most important Greeks == balancing terms of the PDE == free, once you have solved for the pay-off
  \[
  \frac{\partial V}{\partial t} + \frac{1}{2} \sigma^2 S^2 \frac{\partial^2 V}{\partial S^2} + rS \frac{\partial V}{\partial S} - rV = 0
  \]

- Alternating Direction Integration for several factors (stochastic volatility, stochastic rates)

- Boundary conditions can be tricky to formulate and to achieve sufficient accuracy

- Consider handling discontinuities with smoothing techniques (Rannacher, sparse grids)
Tossing a Coin Should Be Carefully Engineered

- Generate Monte Carlo scenarios just once
  - What range of inputs should the scenarios cover? At what time-step?
  - How do you calculate the Greeks and provide for stress tests?
  - Is there a role for importance sampling or other advanced techniques?

- Adapted numeric methods for stochastic differential equations
  - Strong versus weak convergence of numeric SDE solvers
  - **Taming** of processes that can run away, such as square-root diffusions
  - What is the order of the selected method for SDE?
  - Handle accuracy of a solution in **multi-level** approach:
    - Scenarios $n$, $N$, time-steps $dt$, $dT$ ($n << N$, $dt << dT$)
    - Accurate path integration: $n \times dt$ (minimize discretization error)
    - Diversifying away the random error: $N \times dT$ (minimize sampling error)
    - Fine-tune not $N \times dt$ but rather **optimize** $n \times dt + N \times dT$ for cheapest accuracy

- Least squares Monte Carlo
  - Think through how you obtain Greeks, how you accommodate stress tests, early on
  - Inspired choice of **basis functions** which could be “replicating portfolios” — get asymptotic behavior right
  - Quantify accuracy of the LSMC, **numerical experiments are insufficient**
Automatic Differentiation: a Smooth Ride

- **Symbolic differentiation or interval methods or hyper-dual numbers?**
  - \( d \) (for \( i = 0; i < n; f(i++) \) == for \( i = 0; i < n; (df)(i++) \))
  - \( f([a : b]) = [f(a) : f(b)] \) (for \( f \) monotonically increasing)
  - \( df(a + b.i + c.j + d.k) \) (Taylor expansion on hyper-dual arithmetic)

- **Forward or backward adjoint**: input and output dimensions determine approach

- **Include calibration?**
  - From market data to parametric model: derive and compute **Hessian** through AD
  - From parametric model to financial pay-off: AD
  - From **market data to financial pay-off** with the chain rule: \( AD \times AD = AD \)

- **True benchmark — Automatic Differentiation for full trading books**

- **The mathematical case is easily proven, yet the implementation may fail**
  - Discontinuities and kinks are common in financial pay-offs
  - **Memory storage and retrieval** versus computational cost, even for well-behaved problems
Collateral Management – a Primer

- Clear Path Analysis study: “Collateral Management for Institutional Investors”
