

Lesson 45: Derivatives Technology

Module 4: Traditional Digital Finance

Digital Finance Course

2025

- Understand derivatives pricing and risk systems architecture
- Analyze futures and options trading platforms
- Examine OTC derivatives lifecycle and central clearing (CCPs)
- Evaluate EMIR and Dodd-Frank technology requirements
- Assess margin systems and collateral optimization

Derivatives Market Landscape

Market Size (BIS, June 2024):

- OTC Derivatives: \$715 trillion notional outstanding
 - Interest rate derivatives: \$590T (82%)
 - FX derivatives: \$100T (14%)
 - Equity derivatives: \$7T (1%)
 - Credit derivatives: \$9T (1%)
 - Commodity derivatives: \$2T
- Exchange-Traded Derivatives: 45 billion contracts (2023)
 - Futures: 30B contracts
 - Options: 15B contracts

Trading Venues:

Exchange-Traded:

- CME Group: Rates, equity indices, commodities, FX
- Eurex: European equity and rates derivatives
- ICE: Energy, agriculture, financial futures
- Cboe: Equity options, VIX futures

OTC:

- Bilateral negotiation (historically)
- SEFs (Swap Execution Facilities) - US
- MTFs (Multilateral Trading Facilities) - EU
- Electronic platforms: Bloomberg SEF, Tradeweb, MarketAxess

Post-2008 trend: 75%+ of interest rate swaps now cleared via CCPs (vs 20% pre-crisis)

Derivatives Product Types

Futures:

- Standardized exchange-traded contracts
- Daily mark-to-market and margin
- **Financial:** Equity indices (E-Mini S&P), rates (Eurodollar), FX
- **Commodities:** Oil (WTI, Brent), metals (gold), agriculture (corn, wheat)

Options:

- **Call:** Right to buy at strike price
- **Put:** Right to sell at strike price
- **American:** Exercise any time before expiry
- **European:** Exercise only at expiry
- **Exotic:** Barriers, Asians, lookbacks, digitals

Swaps:

- **Interest Rate Swaps (IRS):** Fixed-for-floating (LIBOR/SOFR)
- **Cross-Currency Swaps:** Principal and interest in different currencies
- **Equity Swaps:** Index return vs floating rate
- **Commodity Swaps:** Fixed price vs floating (spot)

Credit Derivatives:

- **CDS (Credit Default Swaps):** Insurance against default
- **Index CDS:** CDX (US), iTraxx (Europe)
- **Tranches:** First-loss, mezzanine, senior

IRS: Most liquid OTC derivative (80%+ of notional outstanding)

Derivatives Pricing Models

Equity Options (Black-Scholes):

$$C = S_0 N(d_1) - Ke^{-rT} N(d_2)$$

$$P = Ke^{-rT} N(-d_2) - S_0 N(-d_1)$$

where

$$d_1 = \frac{\ln(S_0/K) + (r + \sigma^2/2)T}{\sigma\sqrt{T}}$$

$$d_2 = d_1 - \sigma\sqrt{T}$$

Inputs: S_0 = spot price, K = strike, r = risk-free rate, σ = volatility, T = time to expiry

Limitations:

- Constant volatility assumption (implied vol smile/skew observed)
- No early exercise (American options need binomial/FDM)
- No dividends in simple version

Interest Rate Swaps:

Fixed Leg PV:

$$PV_{fixed} = N \times c \times \sum_{i=1}^n \tau_i \times DF(t_i)$$

Floating Leg PV:

$$PV_{float} = N \times \sum_{i=1}^n F(t_{i-1}, t_i) \times \tau_i \times DF(t_i)$$

where N = notional, c = fixed coupon, τ_i = accrual fraction, $DF(t_i)$ = discount factor, F = forward rate

Par Swap Rate:

$$c = \frac{1 - DF(T_n)}{\sum_{i=1}^n \tau_i \times DF(t_i)}$$

Curve Construction:

- Bootstrap discount curve from market instruments (deposits, FRAs, swaps)
- Multi-curve framework post-2008 (OIS discounting vs LIBOR/SOFR projection)

Greeks and Risk Management

First-Order Greeks:

Delta (Δ): Sensitivity to underlying price

$$\Delta = \frac{\partial V}{\partial S}$$

Call delta: 0 to 1, Put delta: -1 to 0

Vega (\mathcal{V}): Sensitivity to volatility

$$\mathcal{V} = \frac{\partial V}{\partial \sigma}$$

Long options: positive vega (benefit from vol increase)

Theta (Θ): Time decay

$$\Theta = \frac{\partial V}{\partial t}$$

Typically negative (options lose value over time)

Rho (ρ): Interest rate sensitivity

$$\rho = \frac{\partial V}{\partial r}$$

Second-Order Greeks:

Gamma (Γ): Curvature of delta

$$\Gamma = \frac{\partial^2 V}{\partial S^2} = \frac{\partial \Delta}{\partial S}$$

Maximum at-the-money, near expiry (high gamma risk)

Vanna: Delta sensitivity to volatility

$$\text{Vanna} = \frac{\partial^2 V}{\partial S \partial \sigma}$$

Volga (Vomma): Vega sensitivity to volatility

$$\text{Volga} = \frac{\partial^2 V}{\partial \sigma^2}$$

Portfolio Greeks Aggregation:

- Sum across positions for linear Greeks (Delta, Vega)
- Gamma concentration risk (short gamma in crash)
- Hedge Greeks dynamically (delta-neutral, vega-neutral)

Derivatives Valuation Systems

System Architecture:

Core Components:

- **Trade Capture:** Front-office booking (Murex, Calypso, Summit)
- **Market Data:** Live and historical prices, curves, vols
- **Pricing Library:** Quantitative models (C++/Python)
- **Risk Engine:** Calculate sensitivities and VaR
- **P&L Attribution:** Explain daily P&L by risk factor
- **Valuation Adjustments:** XVA (CVA, FVA, MVA)

Calculation Methods:

- **Closed-Form:** Black-Scholes, bond formulas
- **Lattice:** Binomial/trinomial trees for American options
- **Finite Difference:** PDE solvers for complex derivatives
- **Monte Carlo:** Path-dependent, multi-asset options

Leading Platforms:

- **Murex (Global):** Front-to-risk for derivatives
- **Calypso:** Multi-asset capital markets
- **SunGard (FIS) Adaptiv:** Counterparty risk and CVA
- **Numerix:** Pricing analytics and XVA
- **Bloomberg DLIB:** Derivatives pricing library
- **QuantLib:** Open-source quantitative finance (C++)

Performance Optimization:

- **Grid Computing:** Distribute Monte Carlo simulations
- **GPU Acceleration:** 10-100x speedup for pricing
- **AAD (Adjoint Algorithmic Differentiation):** Fast Greeks
- **Approximations:** Least-squares Monte Carlo, proxy models

Large bank derivatives book: 100k-1M positions, EOD risk calc in 2-4 hours

Futures Trading Platforms

Major Futures Exchanges:

CME Group:

- CME Globex electronic platform
- Products: E-Mini S&P, Eurodollar, Treasury futures, FX, commodities
- Avg daily volume: 25-30 million contracts (2024)
- Latency: 50-100 microseconds (co-located)

Eurex:

- European equity index futures (DAX, Euro Stoxx)
- Fixed income (Bund, Schatz, Bobl)
- T7 matching engine

ICE Futures:

- Energy: WTI crude, Brent, natural gas
- Agriculture: Sugar, coffee, cotton
- Financial: FTSE, MSCI indices

Futures Trading Technology:

Order Types:

- Outright: Single contract month
- Calendar spreads: Long one month, short another
- Butterfly: 1-2-1 ratio across 3 maturities
- Inter-commodity spreads: Related contracts (e.g., crack spread)

Execution Venues:

- Exchange electronic (CME Globex, Eurex T7)
- Broker platforms (CQG, Trading Technologies, Bloomberg EMSX)
- Algorithmic execution (VWAP, TWAP for large orders)
- Direct market access (DMA) for speed

Market Making:

- HFT firms provide liquidity (Citadel, Virtu, Jump)
- Capture bid-ask spread (1-2 ticks typically)
- Delta-hedge with underlying or options

Options Trading and Volatility Markets

Options Exchanges:

US:

- **Cboe:** Largest options exchange, VIX futures/options
- **ISE (Nasdaq):** Electronic equity options
- **NYSE Arca:** Equity and ETF options
- **MIAX, PHLX, BOX, BZX:** Regional and new entrants

Europe:

- **Eurex:** Equity index options (ODAX, OESX)
- **Euronext:** Individual equity options

Options Volume:

- US equity options: 10-12 billion contracts/year (2024)
- 50%+ volume in SPY, QQQ, AAPL, TSLA
- 0DTE (zero days to expiry) options: 40-50% of SPX volume (2024)

Volatility Trading:

Implied Volatility Surface:

- Volatility varies by strike (smile/skew) and tenor
- **At-the-Money (ATM):** Reference volatility
- **Out-of-the-Money Puts:** Higher vol (tail risk premium)
- **Skew:** Put vol - call vol (negative for equities)

VIX (CBOE Volatility Index):

- 30-day implied volatility of S&P 500 options
- Weighted average of OTM calls and puts
- Typically 12-20 (calm), spikes to 40-80 (crisis)
- VIX futures and options tradeable (hedge tail risk)

Variance Swaps:

$$\text{Payoff} = N \times (\sigma_{\text{realized}}^2 - K_{\text{var}})$$

where N = variance notional, K_{var} = strike variance, σ_{realized} = realized volatility

Pre-Trade:

- ① **Credit Check:** Verify counterparty limits
- ② **Legal Documentation:** ISDA Master Agreement, CSA
- ③ **Pricing:** Request quotes from dealers (RFQ)
- ④ **Negotiation:** Economic terms (notional, tenor, fixed rate)

Execution:

- ⑤ **Trade Capture:** Book in derivatives system (Murex, Calypso)
- ⑥ **Trade Confirmation:** Electronic (MarkitServ, AcadiaSoft) or manual
- ⑦ **Trade Reporting:** Regulatory (EMIR, Dodd-Frank) to TR

Post-Trade:

- ⑧ **Clearing Determination:** Mandatory clearing (standardized) or bilateral
- ⑨ **Novation to CCP:** If cleared, CCP becomes central counterparty
- ⑩ **Margin:** Initial and variation margin posting
- ⑪ **Valuation:** Daily mark-to-market (independent price verification)
- ⑫ **Lifecycle Events:** Resets, coupons, compressions, amendments
- ⑬ **Termination:** Maturity or early unwind

ISDA Documentation:

- Master Agreement: Legal framework for all trades
- Schedule: Customizations (jurisdiction, netting, events of default)
- CSA (Credit Support Annex): Collateral terms
- Confirmations: Trade-specific economics

Central Counterparty Clearing (CCPs)

CCP Clearing Mandate (Post-2008):

Dodd-Frank (US):

- Mandatory clearing for standardized swaps
- SEF trading requirement (pre-trade transparency)
- Trade reporting to Swap Data Repositories (SDRs)

EMIR (EU):

- Clearing obligation for IRS (EUR, GBP, USD), index CDS
- Reporting to Trade Repositories (TRs)
- Risk mitigation for non-cleared (margin, dispute resolution)

Clearing Rate (2024):

- Interest rate swaps: 75-80% cleared
- Credit derivatives: 50-60% (index CDS higher)
- FX derivatives: 5-10% (mostly bilateral)

Major CCPs:

LCH (LSEG):

- SwapClear: \$500T+ notional (IRS, OIS, FRAs)
- CDSClear: Index and single-name CDS
- RepoClear: Repo and securities lending

CME Clearing:

- IRS clearing (US and global)
- Futures and options across all asset classes

ICE Clear:

- ICE Clear Credit: CDS clearing (North America, Europe)
- ICE Clear Europe: Energy and commodity derivatives

CCP Risk Management:

- Initial margin (SPAN, VaR-based)
- Variation margin (daily MTM settlement)
- Default fund (mutualized loss-sharing)
- Stress testing and concentration limits

Margin and Collateral Systems

Initial Margin (IM):

CCP IM Calculation:

- **SPAN (Standard Portfolio Analysis of Risk):** CME method
 - Scenario-based approach (16+ price/vol scenarios)
 - Accounts for offsets within product families
- **VaR-Based:** LCH, Eurex (99% 5-day VaR)
- **Expected Shortfall:** Emerging standard (coherent measure)

Non-Cleared IM (UMR):

- Uncleared Margin Rules (Basel/IOSCO, BCBS-IOSCO 2015)
- Mandatory for firms with \$50B+ derivatives notional
- Phased implementation (2016-2023)
- SIMM (Standard Initial Margin Model): ISDA standard
- Segregation requirement: Third-party custodian

Variation Margin (VM):

- Daily exchange of collateral based on MTM
- Mandatory for all OTC derivatives (Dodd-Frank, EMIR)
- Cash or high-quality securities (government bonds)
- Dispute resolution (valuation differences)

Collateral Optimization:

- **Cheapest-to-Deliver:** Post lowest-opportunity-cost asset
- **Substitution:** Replace collateral to free up better assets
- **Transformation:** Borrow higher-quality collateral (upgrade trades)
- **Triparty Agents:** BNY Mellon, Euroclear manage pools

Technology Platforms:

- **AcadiaSoft:** Margin calculation and optimization
- **CloudMargin:** Collateral management platform
- **Calypso Margin:** Integrated with trade processing
- **TriOptima (CME):** Compression and optimization

EMIR Reporting Requirements

European Market Infrastructure Regulation (EMIR):

Reporting Obligations:

- **Scope:** All derivatives (OTC and exchange-traded)
- **Counterparties:** Both sides report (or delegate)
- **Timing:** T+1 (next working day)
- **Destination:** Trade Repositories (TRs)
- **Fields:** 203 fields (EMIR REFIT, 2024)

EMIR REFIT (2024):

- Simplified reporting for smaller firms
- Standardized data formats (ISO 20022)
- UTI (Unique Trade Identifier) mandatory
- LEI (Legal Entity Identifier) for all counterparties
- Backloading of historical trades

Trade Repositories (TRs):

- **DTCC GTR (Global Trade Repository):** Multi-asset
- **UnaVista (LSEG):** EMIR and MiFID II reporting
- **Regis-TR:** European focused
- **CME Trade Repository:** Commodities and derivatives

Reporting Challenges:

- Data quality (reconciliation breaks)
- Lifecycle event reporting (amendments, compressions)
- Backloading for old trades
- Cross-border coordination (EMIR vs Dodd-Frank)
- LEI adoption and validation

Vendor Solutions:

- Cappitech, ABIDE Financial, Primatics
- Integrated with derivatives platforms (Murex, Calypso)

Dodd-Frank Swap Data Reporting

Dodd-Frank Act (2010):

Title VII - Derivatives:

- Mandatory clearing for standardized swaps
- SEF (Swap Execution Facility) trading
- Swap Data Repository (SDR) reporting
- Enhanced capital and margin (Volcker Rule)

Reporting Requirements:

- **Part 45:** Real-time reporting to SDRs
- **Part 43:** Public dissemination (anonymized)
- **Reporting Parties:** Swap dealers (SDs), major participants (MSPs)
- **Timing:** As soon as technologically practicable (minutes)
- **Block Trades:** 15-minute delay for large notional

Swap Data Repositories (SDRs):

- **DTCC SDR:** Credit, equity, rates
- **CME SDR:** Commodities, FX
- **ICE Trade Vault:** Multi-asset

SEF Trading:

- Electronic platforms for swap execution
- Bloomberg SEF, Tradeweb, MarketAxess, ICE Swap Trade
- Pre-trade transparency (executable quotes)
- Request-for-quote (RFQ) dominant model

Harmonization Efforts:

- CFTC-ESMA cooperation (cross-border)
- Substituted compliance (equivalence)
- UTI and UPI standards (global identifiers)
- Critical trade information (CTI) standardization

LIBOR Cessation (2021-2023):

- USD LIBOR ended June 30, 2023
- GBP, EUR, CHF, JPY LIBOR ended Dec 31, 2021
- Legacy contracts: Fallback language (ISDA protocol)
- Estimated \$300+ trillion notional affected globally

Replacement Rates:

- **USD:** SOFR (Secured Overnight Financing Rate)
- **GBP:** SONIA (Sterling Overnight Index Average)
- **EUR:** ESTR (Euro Short-Term Rate)
- **CHF:** SARON (Swiss Average Rate Overnight)
- **JPY:** TONAR (Tokyo Overnight Average Rate)

SOFR Characteristics:

- Overnight rate (vs forward-looking LIBOR tenors)
- Based on Treasury repo transactions (\$1T+ daily volume)
- No credit risk premium (secured rate)
- Requires compounding for term rates (Term SOFR available)

Technology Impact:

- **Curve Construction:** Multi-curve framework (OIS discounting, SOFR projection)
- **Fallback Implementation:** ISDA fallback spreads, waterfall logic
- **Historical Data:** Limited SOFR history (started 2018)
- **Systems Upgrade:** Pricing, risk, reporting systems updated
- **Vendor Solutions:** Bloomberg, Refinitiv SOFR calculators

CME SOFR futures: \$10+ trillion notional outstanding (2024), primary hedging instrument

DLT and Smart Derivatives Contracts

Blockchain in Derivatives:

Use Cases:

- **Trade Confirmation:** Shared ledger eliminates reconciliation
- **Lifecycle Events:** Automated coupons, resets, terminations
- **Collateral Management:** Real-time margin calls and settlements
- **Regulatory Reporting:** Single source of truth for regulators

Pilot Projects:

- **ISDA CDM (Common Domain Model):** Standardized data model
- **Axonix (AxCore):** Equity swaps post-trade (DTCC partnership)
- **Digital Asset (DAML):** Smart contract language for derivatives
- **Project Guardian (MAS):** Tokenized bonds and FX swaps

Smart Derivatives Contracts:

ISDA Common Domain Model (CDM):

- Machine-executable representation of derivatives
- Event processing (lifecycle automation)
- Legal certainty (code = contract)
- Implemented in DAML, Solidity, Java

Benefits:

- Reduce operational risk (eliminate manual processing)
- Faster settlement (T+0 for collateral)
- Lower costs (remove intermediaries)
- Enhanced transparency (shared audit trail)

Challenges:

- Legal enforceability (code vs traditional contracts)
- Scalability (blockchain performance for high volumes)
- Interoperability (multiple DLT platforms)
- Regulatory acceptance (still evolving)

Summary and Key Takeaways

Derivatives Market:

- \$715T OTC notional (82% interest rate swaps)
- 45B exchange contracts/year (futures + options)
- Post-2008: 75-80% of IRS now cleared via CCPs

Pricing and Risk:

- Black-Scholes for equity options (constant vol limitation)
- Greeks: Delta, gamma, vega for risk management
- Platforms: Murex, Calypso, Numerix for valuation
- GPU acceleration: 10-100x speedup for Monte Carlo

Exchange-Traded:

- CME Globex: 25-30M contracts/day (50-100 microsecond latency)
- VIX futures/options for volatility trading
- ODTCE options: 40-50% of SPX volume (2024)

OTC and Clearing:

- ISDA documentation: Master Agreement + CSA
- CCPs: LCH SwapClear (\$500T+), CME, ICE Clear
- Initial margin (SPAN, VaR) + variation margin (daily MTM)
- UMR: Mandatory IM for \$50B+ notional (segregated)

Regulatory Reporting:

- EMIR: 203 fields, T+1 reporting to TRs
- Dodd-Frank: Real-time SDR reporting, SEF trading
- UTI, LEI, UPI standardization for cross-border

Emerging Trends:

- SOFR transition (LIBOR ended 2023): \$300T+ impacted
- ISDA CDM: Machine-executable derivatives contracts
- DLT pilots: Axoni, Digital Asset, Project Guardian