Complex Event Processing: DSL for High Frequency Trading

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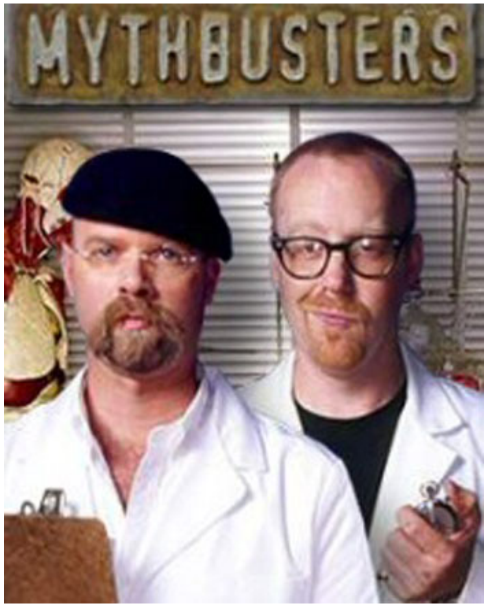
StreamBase Systems

QCon London 2011

Myth: **High level domain specific languages are too slow for HFT.**

Reality: **High level domain specific languages can deliver better performance than system programming languages when tailored to a specific task.**



High Frequency Trading

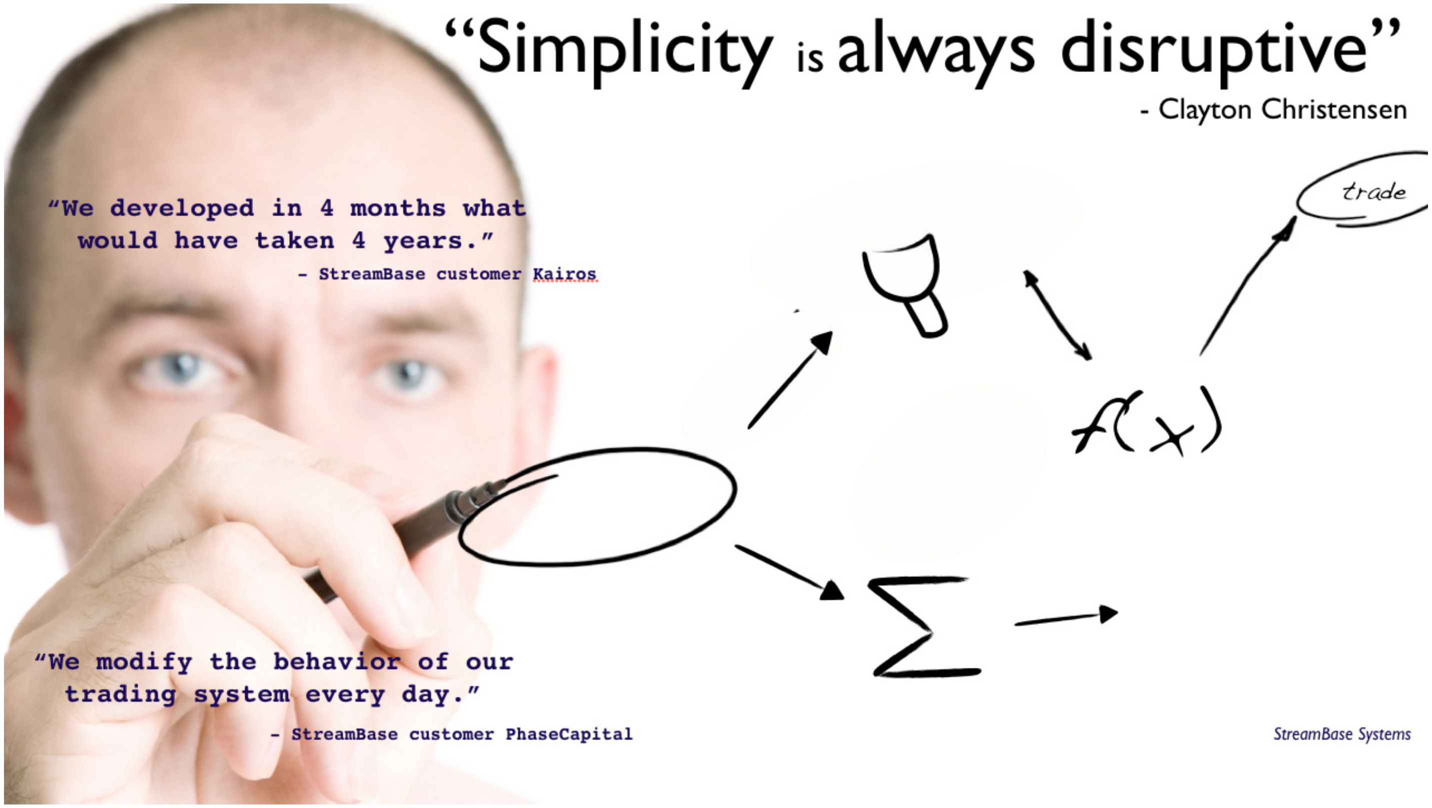
- **Financial trading where latency is critical to profitability**
- **Four Main Scenarios**
  - Alpha seeking – arbitrage
  - Rebate seeking – market making
  - Transaction cost minimization – execution management
  - Service providers – risk management, exchanges
- **Different tolerances for latency across asset class, use cases**
  - Speed to catch opportunity, speed to not get run over, speed to keep customers
- **Most often from scratch in systems programming languages**
  - C++, maybe Java
- **Lots of talk and some use of hardware acceleration, FPGA and GPUs**

Complex Event Processing aka Event Processing

- **Software organized by events (compare object oriented)**
  - What's an event? What's an object?
  - And event is something can trigger processing, can include data.
  - Naturally but not usually represents a "real world" event or observation.
- **Complex Event Processing Platforms**
  - Software stack for event based systems, event driven architectures
  - Event Programming Language – SQL-based, Rules-based, or State-based
  - Commercial and open source: StreamBase, Progress, Microsoft, IBM, Oracle, SAP, Esper, Drools and many more
- **Adopted in financial services and other markets**
  - System monitoring, industrial process, logistics, defense/intelligence
- **Other Event Processing Approaches:**
  - Erlang, Actors, node.js, .NET Rx

Why a DSL?

- **High level**
- **Graphical**
- **Appropriate for purpose**
- **Understandable**
- **Flexible**



"Simplicity is always disruptive"

- Clayton Christensen

"We developed in 4 months what would have taken 4 years."

- StreamBase customer Kairos

"We modify the behavior of our trading system every day."

- StreamBase customer PhaseCapital

Challenges for DSL in HFT

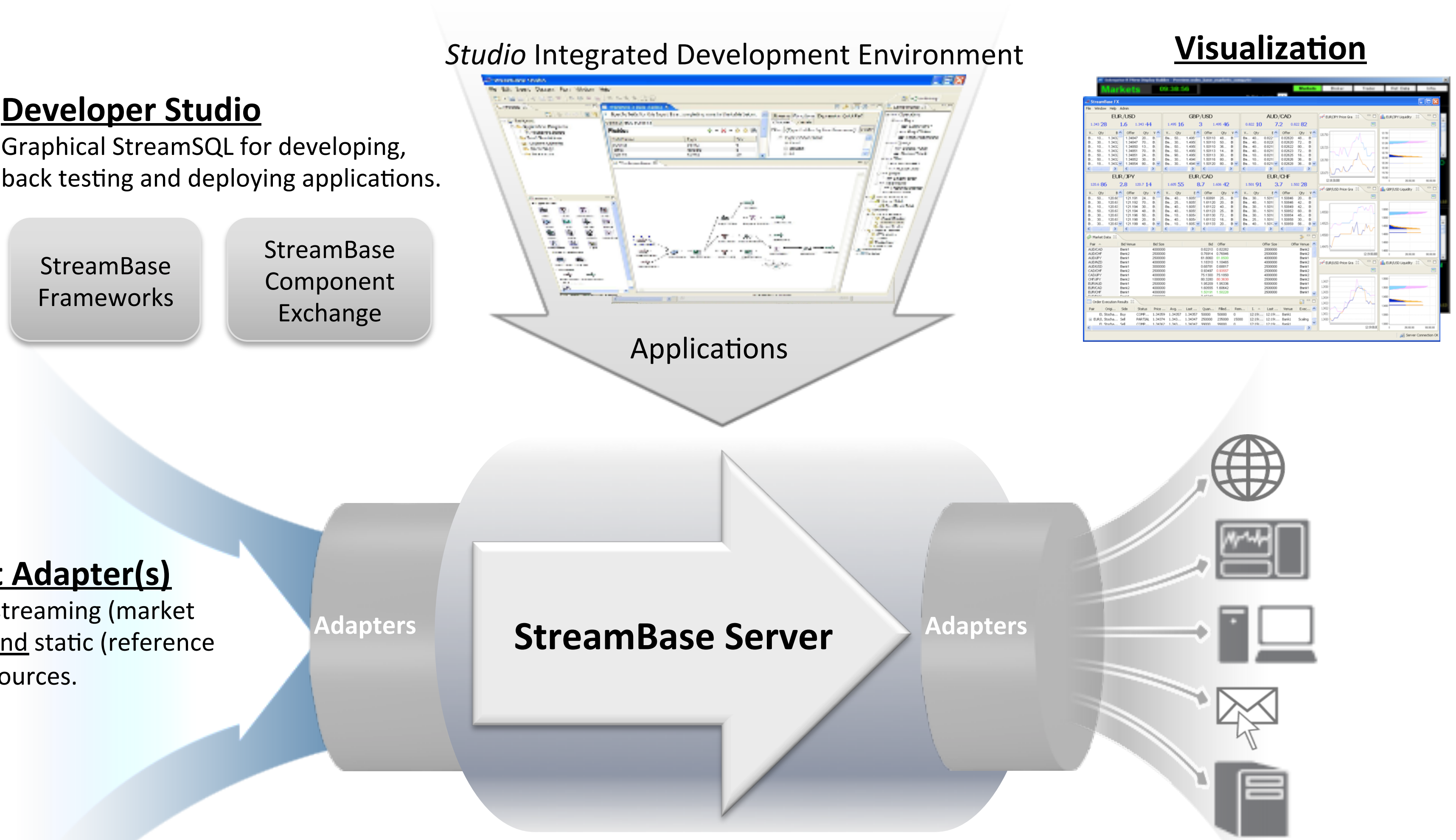
- **Ultra Low Latency**
  - Sub-millisecond is standard, sub-100-micro is desired.
- **Large Data Volumes**
  - Hundreds of thousands of quotes per second, thousands of orders
- **Demanding Operational Environment (in some ways)**
  - Not 24x7, not low touch, but availability during market hours is key
- **Sophisticated Data Processing (sometimes)**
  - Options pricing, yield curves, risk metrics and more

- **See also: LMAX talk from QCon http://bit.ly/fUeS0P**

Agenda

- **Intro: Myth, Reality, HFT, CEP**
- **Benefits of a DSL, Challenges of HFT**
- **StreamBase Accomplishments – Performance and Productivity**
- **Designing a Language for HFT: Performance and Extensibility**
    - Static Analysis
    - Code generation and the Janino compiler
    - Garbage optimization
    - Adapter API, FIX Messaging
    - Parallelism, lanes and tiers
    - Integrations, C++ and Java plugins
- **Lessons Learned**
- **Shameless Plug**
- **Acknowledgements, Questions and Answers**

StreamBase Event Processing Platform



Studio Integrated Development Environment

Visualization

Developer Studio

Graphical StreamSQL for developing, back testing and deploying applications.

Input Adapter(s)

Inject streaming (market data) and static (reference data) sources.

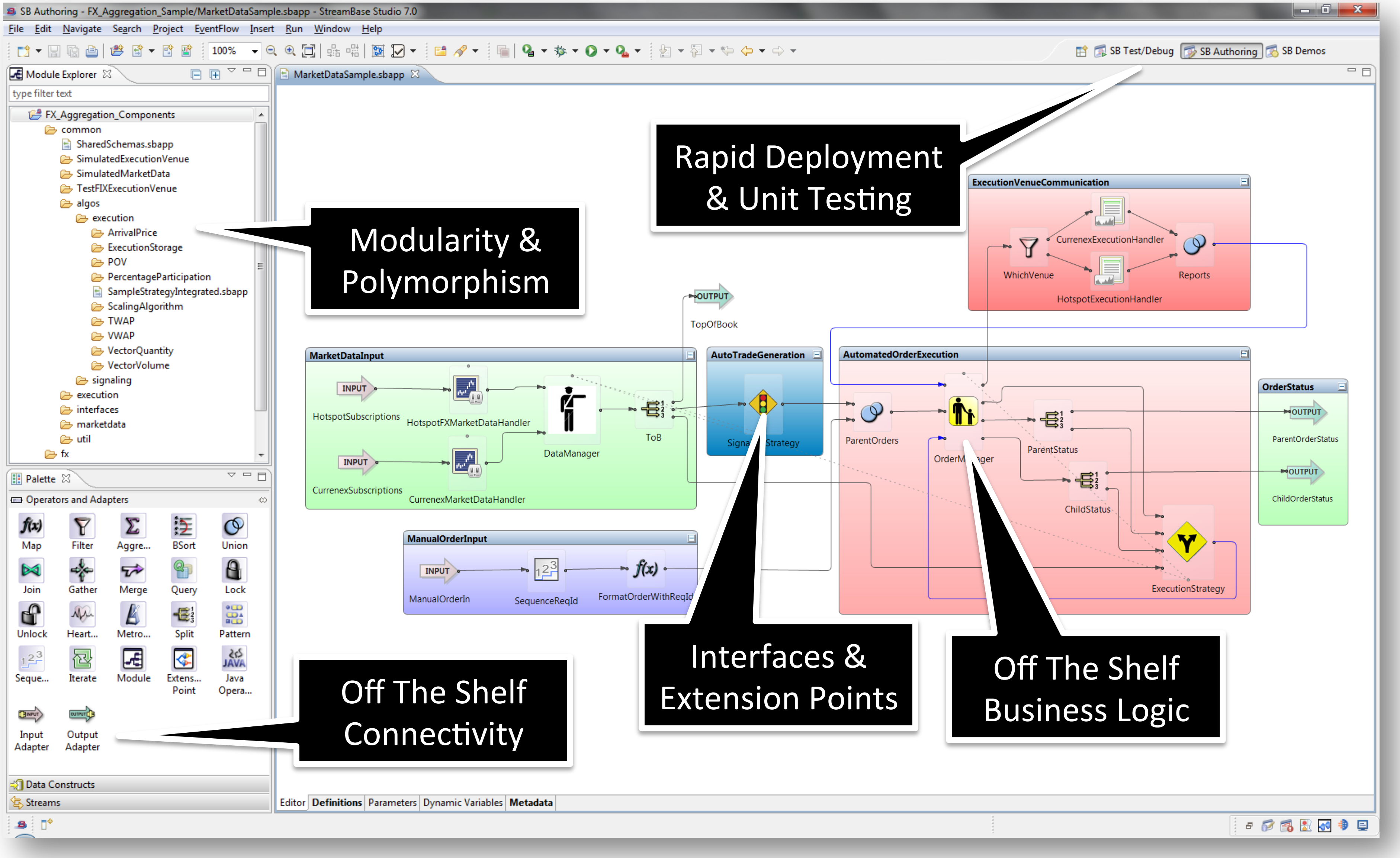
Event Processing Server

High performance optimized engine can process events at market data speeds.

Output Adapter(s)

Send results to systems, users, user screens and databases.

StreamBase StreamSQL EventFlow



Rapid Deployment & Unit Testing

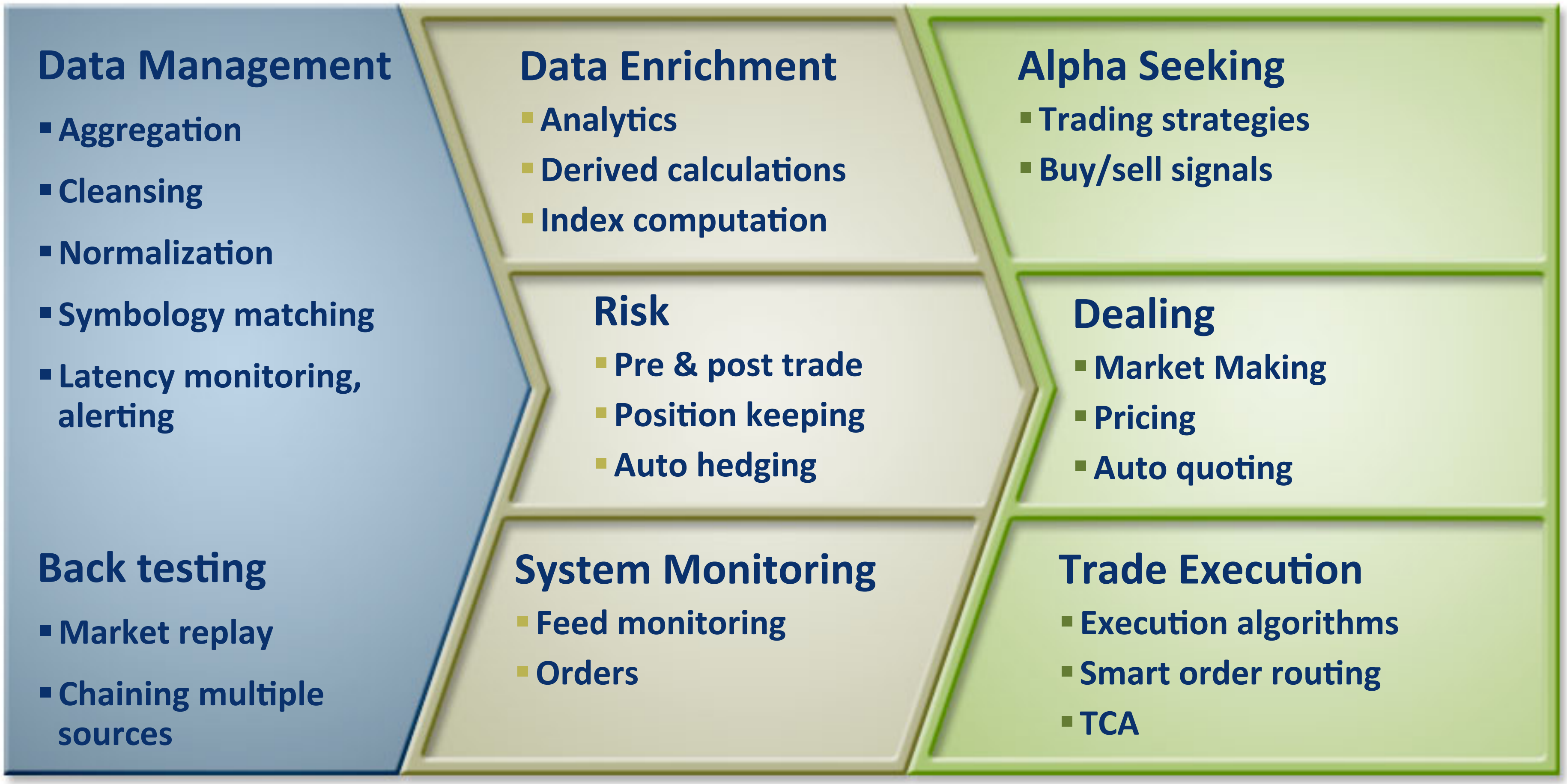
Modularity & Polymorphism

Interfaces & Extension Points

Off The Shelf Business Logic

Off The Shelf Connectivity

Kinds of Applications



Data Management

- Aggregation
- Cleansing
- Normalization
- Symbology matching
- Latency monitoring, alerting

Back testing

- Market replay
- Chaining multiple sources

Data Enrichment

- Analytics
- Derived calculations
- Index computation

Risk

- Pre & post trade
- Position keeping
- Auto hedging

System Monitoring

- Feed monitoring
- Orders

Alpha Seeking

- Trading strategies
- Buy/sell signals

Dealing

- Market Making
- Pricing
- Auto quoting

Trade Execution

- Execution algorithms
- Smart order routing
- TCA

StreamBase Accomplishments Performance & Productivity

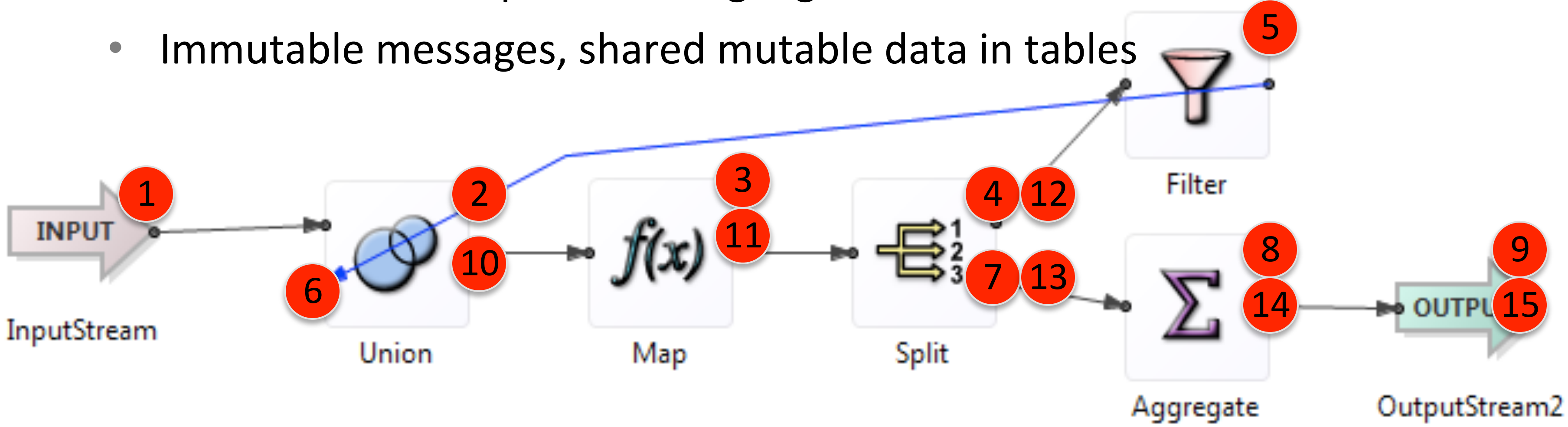
- **Productivity**
  - Don’t reinvent the wheel… or the gaskets, fuel tank, seats, air bag
  - Connectivity (100+ adapters), plumbing, scalability built in
  - Support for agile development process
    - Quants and developers working together
  - Decrease time-to-market and time-to-change 40-90%
    - 10 weeks to 2 days
    - Improved communication, iterative development, business alignment
- **Performance**
  - Ultra low latency – As low as 80 microsecond end to end latency
  - Predictable latency – 99th percentile, minimize outliers
  - High throughput – 100s of thousands of messages per second per core
  - Scale – Horizontally and Vertical, Multi-core and Cluster

How did we do it?

- **Compilation and Static Analysis**
  - Design the language for it
- **Modular abstraction, interfaces**
  - Quants and Developers Collaborate
- **Bytecode generation and the Janino compiler**
  - Optimized bytecodes, in-memory generation
- **Garbage optimization**
  - Pooling, data class, invasive collections
- **Integrations, C++ and Java plugins**
  - Efficient native interfaces
- **Adapter API, FIX Messaging**
  - Threading and API structure for ultra low latency
- **Parallelism, Clustering, Lanes and Tiers**
  - Scalability with latency in mind
- **Named Data Formats, Schemas**
  - Sharing data and semantics between apps

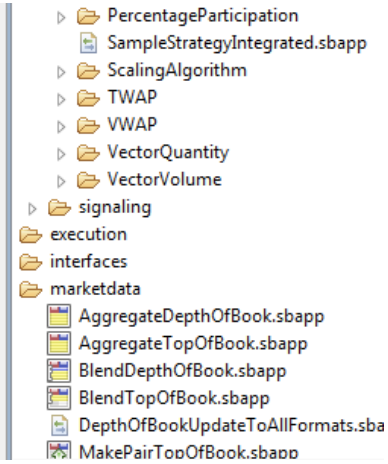
Compilation Static Analysis

- **Design the language for compilation and performance**
  - Static typing, controlled mutation
- **Graphical structure is natural for domain**
  - Statically defined application traversal pattern
- **Avoid listeners, virtual/dynamic dispatch, registration**
  - Except where necessary for extensibility, parallelism
- **Graph defines data sharing**
  - Pure functional expression language
  - Immutable messages, shared mutable data in tables

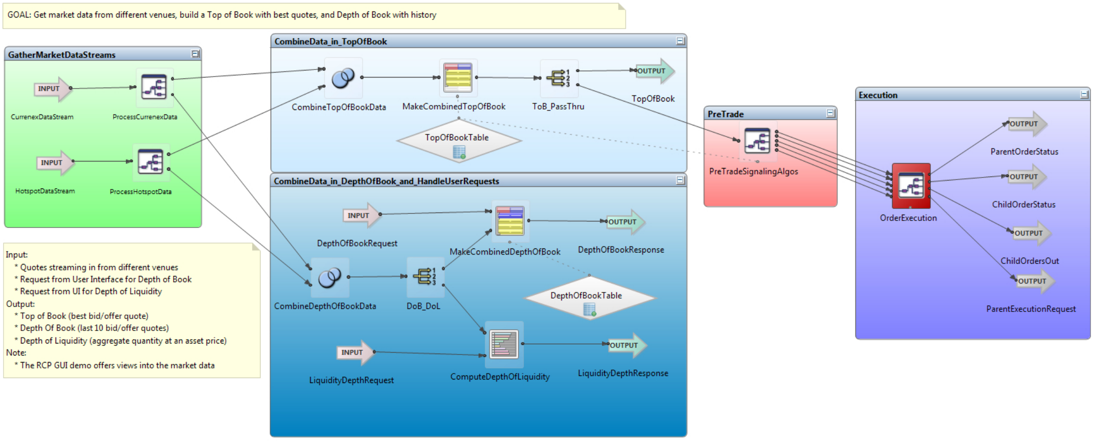


Modular abstraction, interfaces

- **Heterogeneous Teams: Quants and Developers Collaborate**
- **Graphical Language still requires sophisticated abstraction**
  - Modules, parameterization, polymorphism, hygenic macros
- **Interfaces support dependency injection**
- **Back testing and production deployment of same code**
  - Back testing harness uses same interfaces, historical data
- **Allow reuse of infrastructure components across asset classes**
  - Order state management, book building, etc



```
    ▷ PercentageParticipation
      SampleStrategyIntegrated.sbapp
    ▷ ScalingAlgorithm
    ▷ TWAP
    ▷ VWAP
    ▷ VectorQuantity
    ▷ VectorVolume
  ▷ signaling
  execution
  interfaces
  marketdata
    AggregateDepthOfBook.sbapp
    AggregateTopOfBook.sbapp
    BlendDepthOfBook.sbapp
    BlendTopOfBook.sbapp
    DepthOfBookUpdateToAllFormats.sba
    MakePairTopOfBook.sbapp
```

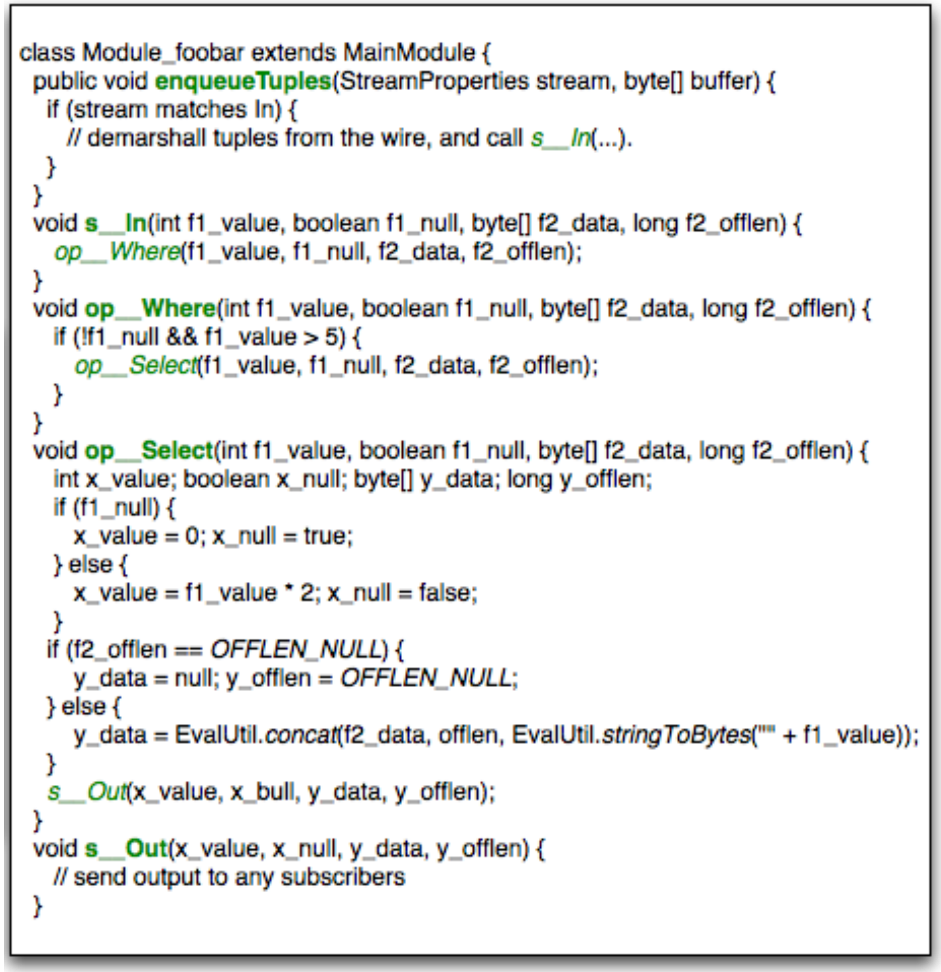


GOAL: Get market data from different venues, build a Top of Book with best quotes, and Depth of Book with history

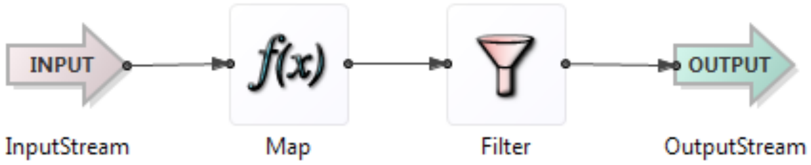
Input:
 * Quotes streaming in from different venues
 * Request from User Interface for Depth of Book
 * Request from UI for Depth of Liquidity
Output:
 * Top of Book (best bid/offer quote)
 * Depth Of Book (last 10 bid/offer quotes)
 * Depth of Liquidity (aggregate quantity at an asset price)
Note:
 * The RCP GUI demo offers views into the market data

Bytecode generation and the Janino compiler

- **Composite data types**
  - Composed of primitive Java data types, arrays
- **Explicit inlining**
- **Monomorphic call sites**
- **Work with the JIT**
- **Calling convention**
  - Introduction of dataclass
  - Queue structures



```
class Module_foobar extends MainModule {
  public void enqueueTuples(StreamProperties stream, byte[] buffer) {
    if (stream matches In) {
      // demarshall tuples from the wire, and call s__In(...).
    }
  }
  void s__In(int f1_value, boolean f1_null, byte[] f2_data, long f2_offlen) {
     op__Where(f1_value, f1_null, f2_data, f2_offlen);
  }
  void op__Where(int f1_value, boolean f1_null, byte[] f2_data, long f2_offlen) {
     if (!f1_null && f1_value > 5) {
        op__Select(f1_value, f1_null, f2_data, f2_offlen);
     }
  }
  void op__Select(int f1_value, boolean f1_null, byte[] f2_data, long f2_offlen) {
     int x_value; boolean x_null; byte[] y_data; long y_offlen;
     if (f1_null) {
        x_value = 0; x_null = true;
     } else {
        x_value = f1_value * 2; x_null = false;
     }
    if (f2_offlen == OFFLEN_NULL) {
        y_data = null; y_offlen = OFFLEN_NULL;
    } else {
        y_data = EvalUtil.concat(f2_data, offlen, EvalUtil.stringToBytes("" + f1_value));
    }
    s__Out(x_value, x_bull, y_data, y_offlen);
  }
  void s__Out(x_value, x_null, y_data, y_offlen) {
     // send output to any subscribers
  }
```

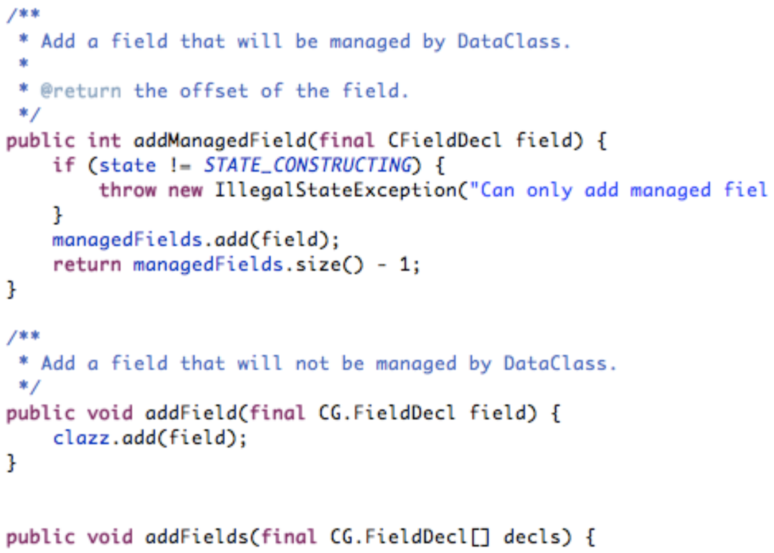


Garbage optimization

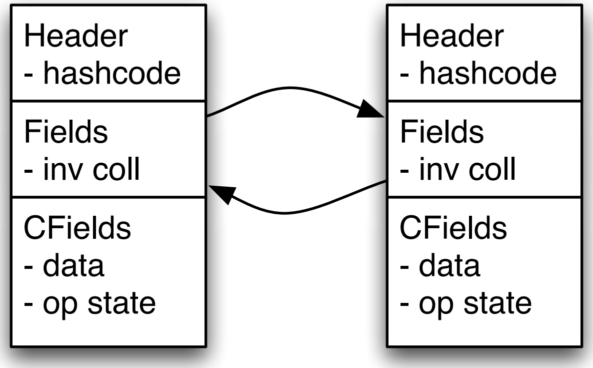
- **All objects live forever or highly transient**
- **Minimize per-event transient objects (to zero)**
  - Test harness to measure per-event garbage
- **Collector tuning**
  - Smaller heaps, smaller young gen, faster promotion for low latency
  - Clustering for large apps in small heaps
- **Primitive data types, infrequently allocated arrays**
- **Test harness for identifying garbage sources**

DataClass

- **A shared struct, all users of the data object inject members**
- **Compiled Tuple Implementation**
  - Efficient access
  - Minimize copying, mutation
- **Invasive Collections**
  - Invasive collections add their own members to DataClass
  - No header objects

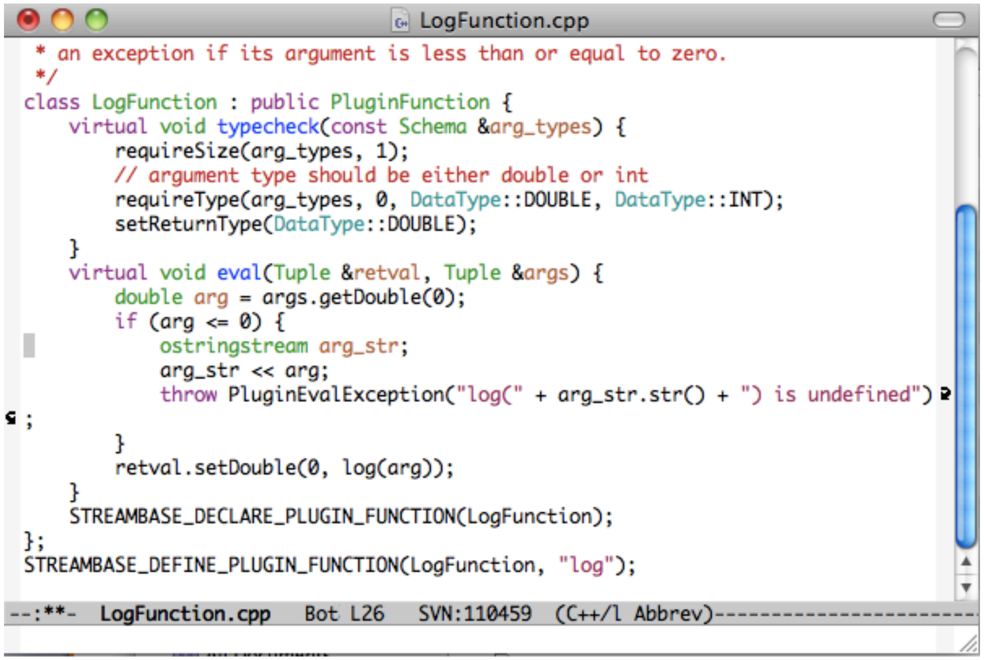


```
/**
 * Add a field that will be managed by DataClass.
 *
 * @return the offset of the field.
 */
public int addManagedField(final CFieldDecl field) {
    if (state != STATE_CONSTRUCTING) {
        throw new IllegalStateException("Can only add managed fiel
    }
    managedFields.add(field);
    return managedFields.size() - 1;
}

/**
 * Add a field that will not be managed by DataClass.
 */
public void addField(final CG.FieldDecl field) {
    clazz.add(field);
}


public void addFields(final CG.FieldDecl[] decls) {
```



Integrations, C++ and Java plugins

- **Efficient native interfaces**
- **JNI does integers and byte buffers. No objects**
  - Tailor C++ APIs to this reality
  - Infrequent resizing
- **Java APIs designed for garbage efficiency**
  - Primitive types
  - Object reuse



```
 * an exception if its argument is less than or equal to zero.
 */
class LogFunction : public PluginFunction {
    virtual void typecheck(const Schema &arg_types) {
        requireSize(arg_types, 1);
        // argument type should be either double or int
        requireType(arg_types, 0, DataType::DOUBLE, DataType::INT);
        setReturnType(DataType::DOUBLE);
    }
    virtual void eval(Tuple &retval, Tuple &args) {
        double arg = args.getDouble(0);
        if (arg <= 0) {
            ostringstream arg_str;
            arg_str << arg;
            throw PluginEvalException("log(" + arg_str.str() + ") is undefined")
;
        }
        retval.setDouble(0, log(arg));
    }
    STREAMBASE_DECLARE_PLUGIN_FUNCTION(LogFunction);
};
STREAMBASE_DEFINE_PLUGIN_FUNCTION(LogFunction, "log");
```

```
--:**-  LogFunction.cpp   Bot L26   SVN:110459  (C++/l Abbrev)----------------------
```

Adapter API, Third Party Integrations

- **Threading and API structure for ultra low latency**
- **Adapter threads carry the message through application processing**
- **Single thread from ingest to output**
  - Requires care to avoid deadlocks in third party libraries
- **Memory management hints in API: reuseTuple, factory methods**
- **Compiled tuple implementation – backed by dataclass**
- **Tightly integrate key messaging technologies**
  - FIX: QuickFIX, Cameron, etc
  - Venues, Hardware acceleration
  - Cluster Messaging: P2P, Solace

activ FINANCIAL

NVIDIA

Lime Brokerage

my-Channels

Solace Systems

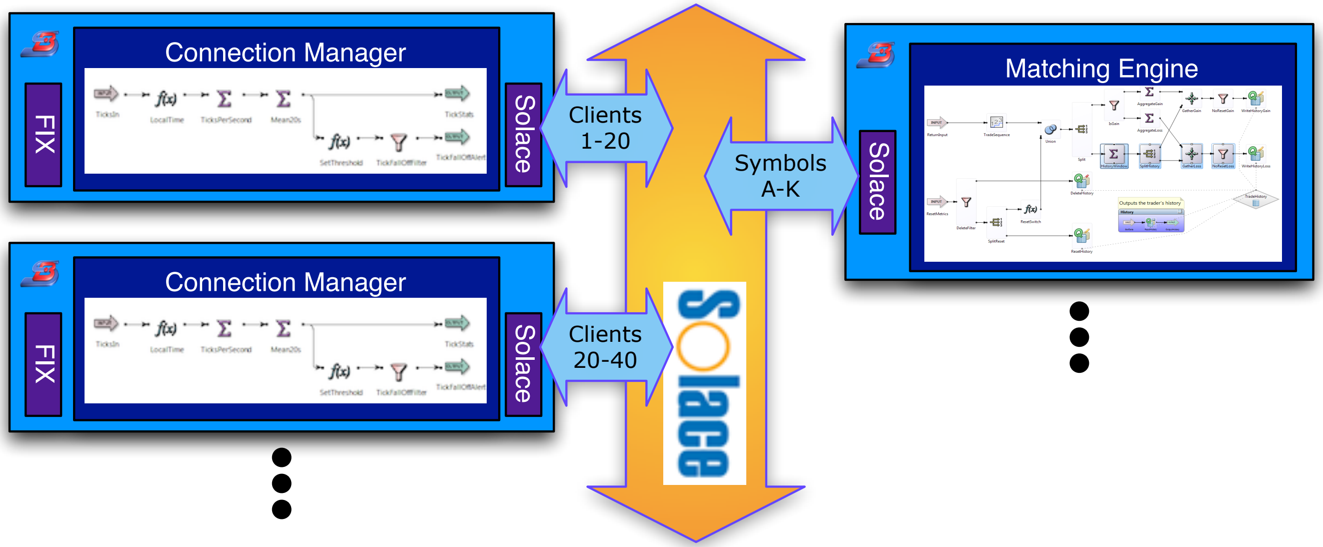
29 WEST INC.

Autobahn

THOMSON REUTERS

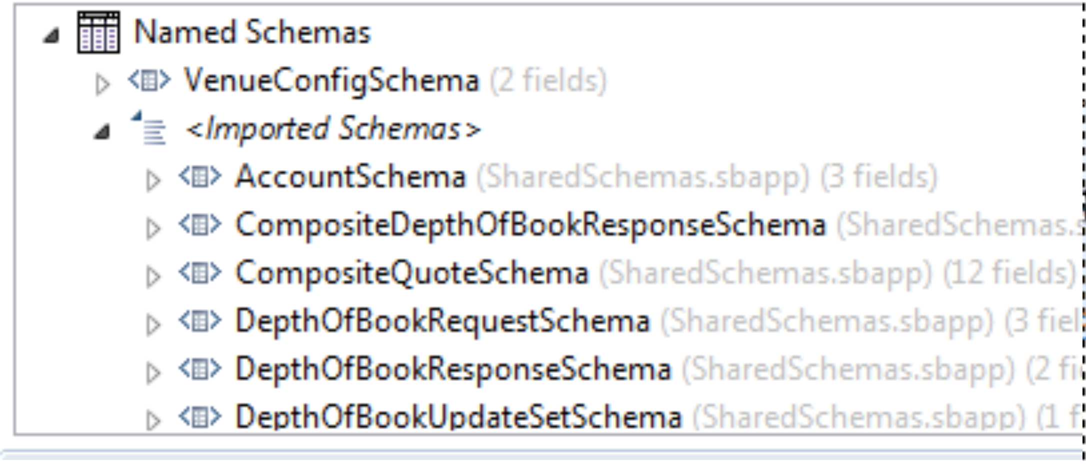
Parallelism, Clustering, Lanes and Tiers

- **Scalability with latency in mind**
- **For low latency, single machine per message, minimize queues**
- **Parallelize in the middleware, e.g. Solace**
- **Lanes offer stable latency when scaling, less efficient hardware utilization**
- **Tiers for efficiency of node-role**

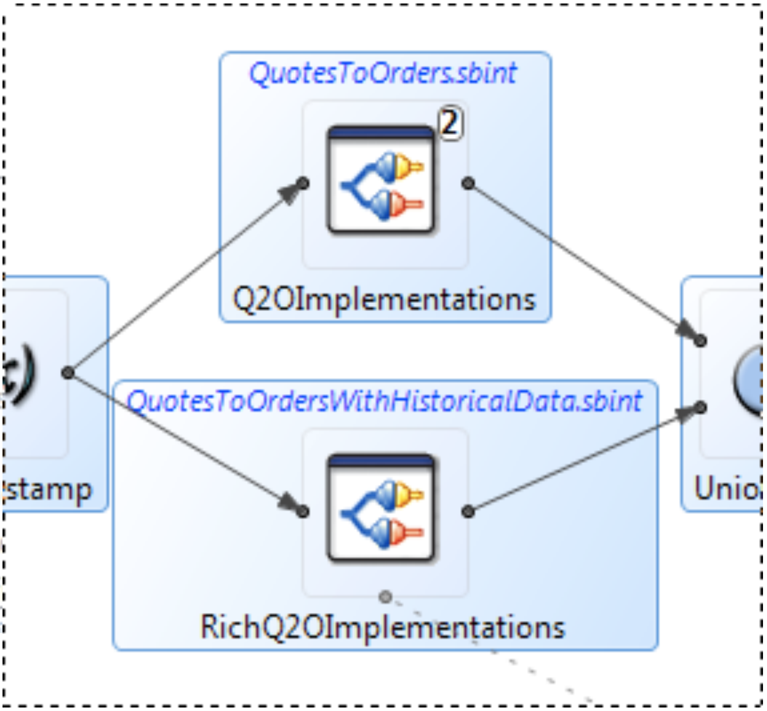


Named Data Formats, Schemas

- **Data formats are key driver of event driven app design**
- **Named schemas for sharing data types, fields, definitions**
- **Basis for Interfaces and Extension Points**
  - Teams combining developers, quants, analysts
- **Non-Flat message model (despite SQL heritage)**
  - Sub-tuples, Lists



- Named Schemas
  - VenueConfigSchema (2 fields)
  - *<Imported Schemas>*
    - AccountSchema (SharedSchemas.sbapp) (3 fields)
    - CompositeDepthOfBookResponseSchema (SharedSchemas.s
    - CompositeQuoteSchema (SharedSchemas.sbapp) (12 fields)
    - DepthOfBookRequestSchema (SharedSchemas.sbapp) (3 fie
    - DepthOfBookResponseSchema (SharedSchemas.sbapp) (2 fi
    - DepthOfBookUpdateSetSchema (SharedSchemas.sbapp) (1 f



Lessons Learned, What Not To Do

- **Messages are fatter than you would think**
  - Particularly internal messages; often have 100-200 fields
- **Overuse of code generation (passive voice)**
  - Not everything needs to be hyper-optimized
  - Favor active voice code, with active voice tests, and passive voice subclasses. Trust in monomorphic call sites and the JIT. But verify.
- **Delayed emphasis on separate compilation**
  - Formalize and test calling convention early
- **Invest in performance measurement**
  - Don't be afraid to have your core engineers writing performance measurement and analysis harnesses

Shameless Plugs

- **StreamBase**
  - You could build one of these yourself, or use ours…
  - Download and test out the full product http:/www.streambase.com
  - Build something and submit to the StreamBase Component Exchange
    - http://sbx.streambase.com
  - Contact us to buy or to an OEM partner, offices London, Boston, New York
  - We're hiring
  - We're training
    - http://www.streambase.com/developers-training-events.htm
- **DEBS – Distributed Event Based Systems**
  - Academic (ACM) Conference outside NYC in July http://debs2011.fzi.de/
- **EPTS – Event Processing Technology Society**
  - http://ep-ts.org industry consortium

Questions?

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