Quantitative Finance Using R
An Overview

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Describe the context within which development is taking place

- How and where R adds value in investing
- Our motivation for writing packages

Show three specific applications using R packages:

- Performance analysis relative to a peer group
- Strategic allocation of a portfolio
- Backtesting of a trading strategy

Discuss further work

- Google Summer of Code
- Areas of continuing development
### Research Process and Capabilities

#### Business View

<table>
<thead>
<tr>
<th>Business Processes</th>
<th>Production</th>
<th>Compliance</th>
<th>Distribution</th>
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<tbody>
<tr>
<td>Innovation</td>
<td>Develop Strategies</td>
<td>Determine Investments</td>
<td>Administer Accounts</td>
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<td>Process Investments</td>
<td>Comply with Regulations</td>
<td>Attract and Retain Investors</td>
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#### Process View

<table>
<thead>
<tr>
<th>Research and Investment Process</th>
<th>Capabilities View</th>
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<tr>
<td>Assess Environment</td>
<td>Strategy Development</td>
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<tr>
<td>Identify Opportunities</td>
<td>Performance Measurement</td>
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<td>Evaluate Opportunities</td>
<td>Performance Attribution</td>
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<tr>
<td>Create Expectations</td>
<td>Risk Measurement</td>
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<tr>
<td>Determine Allocations</td>
<td>Risk Management</td>
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<td>Implement Portfolio</td>
<td>Portfolio Construction</td>
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#### Capabilities View

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<th>Performance Measurement</th>
<th>Performance Attribution</th>
<th>Risk Measurement</th>
<th>Risk Management</th>
<th>Portfolio Construction</th>
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<tr>
<td>What should work?</td>
<td>What has the strategy achieved?</td>
<td>How has the strategy achieved it?</td>
<td>What risks are being taken?</td>
<td>What can we do about risk?</td>
<td>What is the best use of our capital?</td>
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<tr>
<td>What do we think about the environment?</td>
<td>Is performance on track with our expectations?</td>
<td>How does the strategy generate returns?</td>
<td>What risks does the strategy take?</td>
<td>What risks does our portfolio contain?</td>
<td>What are our objectives for return and risk?</td>
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<tr>
<td>What scenarios or themes will affect performance and risk?</td>
<td>How does performance look in context of risk?</td>
<td>Are we skilled or lucky?</td>
<td>What is its sensitivity to the risks?</td>
<td>What is an appropriate level for each risk?</td>
<td>How do we deploy our capital to best meet those objectives?</td>
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<td>Can we effectively tilt our portfolio to capture our views on performance?</td>
<td>How did the strategy compare to its peers?</td>
<td>Are we deviating from what we’ve done in the past?</td>
<td>What risks does the aggregate portfolio contain?</td>
<td>What should we do about them?</td>
<td>Can we design a portfolio for a particular objective?</td>
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<td>What is our “neutral” view?</td>
<td>What is a suitable benchmark for performance?</td>
<td>How confident are we in our assessments?</td>
<td>What is our exposure to extreme risks?</td>
<td>What should we hedge? What should we use / how much to hedge?</td>
<td>Is the level of diversification appropriate?</td>
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</table>
Objectives

Make high quality decisions efficiently, effectively.

Decision-focused information
Repeatable decision-making
Accretion of evidence, statistical confidence
Multiple faceted views
Support fast-cycle experimentation

Tools View

Performance Analysis
Portfolio Tools
Shock Analysis
Multi-Criterion Selection
Proxy Portfolios

Risk Analysis
Sensitivity Analysis
Risk Aggregation
Factor Modeling
Risk Budgeting
What-if Analysis
Backtesting
Optimization
Forecasting

Data Management
## Functional Groupings

<table>
<thead>
<tr>
<th>Functional Grouping</th>
<th>Applications/Reporting</th>
<th>Portfolio</th>
<th>Optimization/Sizing</th>
<th>Modeling/Analytics</th>
<th>Instrument</th>
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### Some R packages for Quantitative Research

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<th>Category</th>
<th>Packages</th>
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<td><strong>Application/Reporting</strong></td>
<td>plot.xts, PerformanceAnalytics, quantmod, Rmetrics</td>
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<tr>
<td><strong>Portfolio</strong></td>
<td>fPortfolio, portfolio, backtest, PortfolioAnalytics</td>
</tr>
<tr>
<td><strong>Optimization/Sizing</strong></td>
<td>PortfolioAnalytics, fPortfolio, portfolio, BLCOP, ROI, DEoptim, psosoma, quantstrat</td>
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<tr>
<td><strong>Modeling/Analytics</strong></td>
<td>TTR, PerformanceAnalytics, quantstrat, etc. (most R packages fit here)</td>
</tr>
<tr>
<td><strong>Instrument</strong></td>
<td>FinancialInstrument</td>
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<tr>
<td><strong>Time series</strong></td>
<td>xts, zoo, timeSeries, its, irts</td>
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<tr>
<td><strong>Data</strong></td>
<td>RBloomberg, RTAQ, Reuters, InteractiveBrokers, tseries (Rmetrics), quantmod</td>
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PerformanceAnalytics

- Focused on returns-based analysis of performance and risk.
- Analysis of return streams, whether distributed normally or not.
- In development since early 2006, packaged and first released to CRAN in 2007
- Collaboration, patches and suggestions from users in industry and academia worldwide
- Contains over 200 functions, including over 30 chart functions and 15 table functions

Over 20,000 lines of code, over 250 pages of documentation and vignettes ...and growing
• Provides numerical solutions to portfolios with complex constraints and objectives

• Unifies the interface into different numerical optimizers

• Implements a front end to two analytical solvers: Differential Evolution and Random Portfolios

• Preserves the flexibility to define any kind of objective and constraint

• Work-in-progress, available on R-Forge in the ReturnAnalytics project
• Designed and used for 'real' quantitative strategies at all frequencies

• Many strategies may be constructed from all open source components

• Proprietary strategies add custom:
  ○ Indicators
  ○ Signal Functions
  ○ Order Sizing Logic

• R packages blotter and FinancialInstrument provide multi-instrument, multi-currency portfolio P&L support
Values represented as:

Returns

- PerformanceAnalytics
- FactorAnalytics

Prices

- quantmod
- TTR

Positions represented as:

Weights

- PortfolioAnalytics

Transactions

- quantstrat
- blotter

Utility

*Time Series*: xts

*Reference Data*: FinancialInstrument
Case Study: Peer Group Analysis

- Accrue evidence to help ask better questions
- Measurement, not prediction
- Consider return and risk together
- Small, biased samples of expensive data
- Comparisons can be tenuous
- Only one of a set of tasks taken to understand a current or potential investment
Distributions

Value at Risk (VaR)

- **Gaussian**
  - Density
  - Empirical Quantiles

- **Skew-T**
  - Density
  - Empirical Quantiles

- **Stable**
  - Density
  - Empirical Quantiles

Comparing VaR to Peers

Comparing Methods

Raw

Cleaned
<table>
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<tr>
<th></th>
<th>Semi Deviation</th>
<th>Gain Deviation</th>
<th>Loss Deviation</th>
<th>Downside Deviation (MAR=10%)</th>
<th>Downside Deviation (r=4%)</th>
<th>Downside Deviation (0%)</th>
<th>Maximum Drawdown</th>
<th>VaR (99%)</th>
<th>Beyond VaR</th>
<th>Modified VaR (99%)</th>
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Case Study: Portfolio Optimization

- Discuss the challenges of constructing hedge fund portfolios
- Offer a framework for considering strategic allocation using hedge fund indexes
- Show the relative performance of multiple objectives
Markowitz (1952) described an investor's objectives as:

- maximizing some measure of gain while
- minimizing some measure of risk.

Many approaches follow Markowitz and use mean return and standard deviation of returns for “risk”.

Most investors would prefer:

- to be approximately correct rather than precisely wrong
- to define risk as potential loss rather than volatility
- the flexibility to define any kind of objective and combine constraints
- a framework for considering different sets of portfolio constraints for comparison through time
- to build intuition about optimization through visualization
Real portfolios more often have complex objectives...

Construct a portfolio that:

- maximizes return,
- with per-asset conditional constraints,
- with a specific univariate risk limit,
- while minimizing component risk concentration,
- and limiting drawdowns to a threshold value.

Not a quadratic (or linear, or conical) problem any more.
Burns (R/Finance 2009) describes Random Portfolios

- From a portfolio seed, generate random permutations of weights that meet your constraints on each asset.

Sampling can help provide insight into the goals and constraints of the optimization

- Covers the 'edge case' (min/max) constraints well
- Covers the 'interior' portfolios
- Useful for finding the search space for an optimizer
- Allows arbitrary number of samples
- Allows massively parallel execution
A very powerful, elegant, population based stochastic function minimizer

- doesn't require a smooth or differentiable function
- Continuous, evolutionary optimization
- Uses real-number parameters
- has shown converging power with difficult, non-convex portfolio problems

**DEoptim** package implements the algorithms described in:

- Thanks to R co-authors David Ardia, Katharine Mullen, and Josh Ulrich
Strategic Allocation

...broadly described as periodically reallocating the portfolio to achieve a long-term goal

- Understand the nature and sources of investment risk within the portfolio
- Manage the resulting balance of risk and return of the portfolio
- Applied within the context of the current economic and market situation
- Think systematically about preferences and constraints
Performance of Indexes

Cumulative Return

Drawdown

Date

Jan 97 Jan 98 Jan 99 Jan 00 Jan 01 Jan 02 Jan 03 Jan 04 Jan 05 Jan 06 Jan 07 Jan 08 Jan 09 Jan 10 Jan 11 Jan 12
Performance of Indexes
Performance of Indexes

From January 1997 to February 2012
Performance of Indexes

From January 1997 to February 2012
Correlation of Indexes

Since Inception

Trailing 36-Months

uses corrplot package
Returns

- ARMA(1,1) to try to capture some of the time varying return structure
- Preserves the observed autocorrelation of the series
- Approaches the long-run means of the series near the end, losing time-varying structure
- Merely illustrative of what is possible with a more sophisticated model
- Model specification close to defaults in `rugarch`

Volatility

- Standard GARCH(1,1) framework
- Uses Dynamic Conditional Correlation to capture interdependencies among the series
- Modeled an asymmetric generalized hyperbolic distribution to allow for coskewness and cokurtosis of the return series
- Used `rmgarch`, little tuning of the specification for this example
4,000 Random Portfolios

as of 2008-06-30

Scatter plot at a date with buoy portfolios
Turnover From Equal Weight

as of 2008-06-30

The graph shows a scatter plot of predicted mean versus predicted standard deviation, with data points distributed across different degrees of turnover from an equal weight portfolio.
Ex Ante Results

as of 2008-06-30
Ex Ante vs. Ex Post Results

2008-06-30 to 2008-09-30
Out of Sample Results

Cumulative Return

Drawdown

Date

Jan 00  Jan 01  Jan 02  Jan 03  Jan 04  Jan 05  Jan 06  Jan 07  Jan 08  Jan 09  Jan 10  Jan 11  Jan 12
Generalize and discuss the architectural elements of a trading system

Describe and implement a simple trend following system

Discuss the role of the packages used
Trade Simulation Tool Chain

Types of Activities

- Connect to database
- Download historical data
- Clean and align data
- Graph prices and indicators
- Calculate indicators
- Transform prices
- Estimate volatility
- Calculate trailing volume
- Estimate pre-trade pricing
- Forecast return
- Forecast risk
- Evaluate rules
- Generate signals
- Optimize portfolio
- Budget risk
- Calculate target position
- Calculate trade size
- Evaluate trading costs
- Specify contract specs
- Capture trades
- Calculate positions
- Calculate P&L
- Aggregate portfolio
- Calculate returns and risk
- Compare to benchmarks
- Provide attribution
- Analyze risk

Example R Packages

quantmod indexing RTAQ xts ... TTR signal-extraction realized ... quantstrat quantmod Rgarch RQuantLib lspm Portfolio-Analytics blotter Financial-Instrument Performance-Analytics
Strategy Specification

Filters
- Determine what instruments to trade
- Applied periodically
- May halt evaluation of trading rules or trading during period
- Examples: Lo's Variance Ratio, 'stock screens'

Indicators
- Quantitative value derived from market data
- Applied in a vectorized or streaming fashion
- Presumed to be able to be calculated in path-independent fashion
- No knowledge of current position or trades
- Examples: moving averages, volatility bands, RSI, MACD, channels, any 'technical analysis indicators'

Signals
- Describe interaction between market data and indicators
- Describe the possible desire for an action, but may not be actionable
- Applied in a vectorized or streaming fashion
- Used to inform rule decisions
- Examples: Crossovers, Thresholds, Multiples

Rules
- Evaluated in a path-dependent fashion
- Have available all market data prior to current observation
- Are aware of current position at time of evaluation
- Generate entry, exit, and risk management orders
- May enter new orders or modify existing orders
- Types: Entry, Exit, Risk, Rebalancing

- Complete specification of the business logic of the strategy
- Sufficient to
  - Model,
  - Test,
  - and Code
- Describes all required components of the strategy
- Should also define data requirements (e.g. tick, BBO, OHLC bars, etc.)
- Typically defined independently of instruments the strategy may be applied to
About the Faber Example

- A very simple trend following strategy:

- Buy when monthly price > 10-month SMA.

- Sell and move to cash when monthly price < 10-month SMA.

- 10 years of monthly data, S&P Sector ETFs.

- No shorting, 'sell' goes to cash

- Positions are fixed.
```r
currency('USD')
symbols = c("XLF", "XLP", "XLE", "XLY", "XLV", "XLI", "XLB", "XLK", "XLU")
for(symbol in symbols) {
  stock(symbol, currency="USD", multiplier=1)
}
getSymbols(symbols, src='yahoo', index.class=c("POSIXt","POSIXct"), from='1998-01-01')
for(symbol in symbols) {
  x<-get(symbol)
  x<-to.monthly(x,indexAt='lastof',drop.time=TRUE)
  colnames(x)<-gsub("x",symbol,colnames(x))
  assign(symbol,x)
}
initPortf('faber', symbols=symbols, initDate='1997-12-31')
initAcct('faber', portfolios='faber', initDate='1997-12-31')
initOrders(portfolio='faber', initDate='1997-12-31')
strategy("faber", store=TRUE)
add.indicator(strategy = 'faber', name = "SMA", arguments = list(x = quote(Cl(mktdta)), n=10), label="SMA10")
add.signal(strategy='faber', name="sigCrossover", arguments = list(data=quote(mktdta), columns=c("Close","SMA"), relationship="gt"), label="Cl.gt.SMA")
add.signal(strategy='faber', name="sigCrossover", arguments = list(data=quote(mktdta), columns=c("Close","SMA"), relationship="lt"), label="Cl.lt.SMA")
add.rule(strategy='faber', name='ruleSignal', arguments = list(data=quote(mktdta), sigcol="Cl.gt.SMA", sigval=TRUE, orderqty=100, ordertype='market', orderside=NULL, threshold=NULL), type='enter')
add.rule(strategy='faber', name='ruleSignal', arguments = list(data=quote(mktdta), sigcol="Cl.lt.SMA", sigval=TRUE, orderqty='all', ordertype='market', orderside=NULL, threshold=NULL), type='exit')
out <- applyStrategy(strategy='faber', portfolios='faber')
updatePortf(Portfolio='faber')
```

**Code Color Key:**
- Financial-Instrument
- quantmod
- blotter
- quantstrat
- TTR
- xts

No custom code

run
demo('faber')
from inside R
Faber Results

For individual positions...

...and the resulting portfolio

chart.Posn( )

charts.PerformanceSummary( )
● Additional Metrics from Bacon (2008) for PerformanceAnalytics
● Portfolio attribution from Cristopherson, Carino, and Ferson (2009)
● Functionality from Attilio Meucci's Factors on Demand and other papers
● Additional closed form optimizer backends for PortfolioAnalytics
● Improvements to xts visualization and subsetting
● Extensions to RTAQ for high frequency time series analysis
Future Development

- **FactorAnalytics**
  - Lead by Prof. Eric Zivot, recently added to R-Forge

- **Possibilities for next summer?**
  - Data Envelopment Analysis (DEA) for relative performance measurement
  - Parameter optimization for quantstrat
  - Continued refinement of reporting frameworks

- **CRAN releases for**
  - PerformanceAnalytics 1.1
  - blotter, FinancialInstrument, quantstrat
  - PortfolioAnalytics

- **Future research**