Quantitative Investment: Research and Implementation in MATLAB

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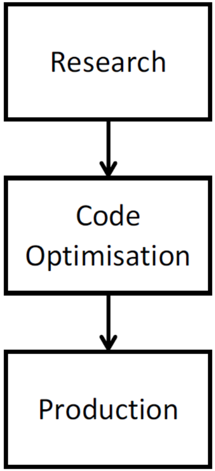
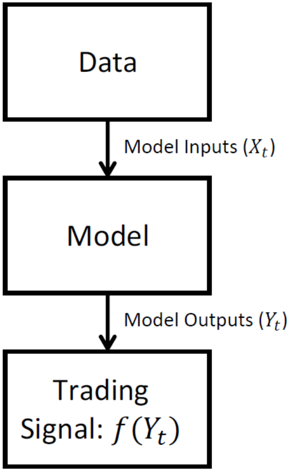
Trading Strategy Workflow



1. **Research**
   - Identification of returns source and robust modelling
   - Robust testing of trading signals
   - Possibly multiple data sources
   - MATLAB: Scripting, charting, reporting
2. **Code Optimisation**
   - Speed improvements
   - Identification and removal of unnecessary processing or data querying
   - MATLAB: Documentation, practice/experience
3. **Production**
   - Set of guidelines for production code
   - Central data source
   - MATLAB: Functions, OO

Generic Trading Strategy



1. **Data**
   - Historical and real-time
   - Financial, economic, sentiment, etc.
2. **Model**
   - Simplification of reality which captures certain important features
   - E.g. use inflation and growth to forecast bond yields
   - E.g. high-yielding currencies appreciate against low-yielding currencies
   - E.g. asset-price trends are persistent
3. **Trading signal**
   - Convert model outputs into trading positions
   - Which assets to buy and sell, and in what quantities
   - Position sizing may be dependent on risk or regulatory constraints

Research

Starting a Project

1. Idea generation
   - ‘In house’
   - From literature (broker or academic research)
   - Anecdotal evidence
     - ‘Buy/sell Bund futures following declines/rises in the flash manufacturing PMI’
     - Some technical analysis (e.g. support/resistance levels)
2. Model specification
   - What are the required outputs?
   - What should be input?
   - Can the model be simplified without compromising on its most important features?
3. Data gathering
   - Central banks
   - Financial data providers
   - Websites
   - Brokers

Personal Modelling Philosophy
A Digression

I learnt this the hard way:

> *If a simple trading model can be shown to work, a complicated model* ***may*** *improve results.*
>
> *If no simple trading model can be shown to work, no complicated model will improve results.*

This does not mean that building successful trading models is easy. As is typical in research, 90% of the work is finding the right questions to ask; the other 10% is finding answers.

Research
Fitting Models

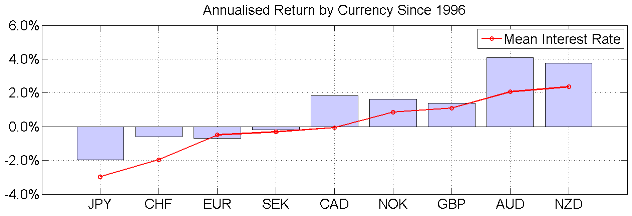
Robustness checks

- Sensitivity of model output to parameters
- Stability of parameters
  - Do different fitting methods produce similar results?
  - How sensitive are parameters to the data sample?
- Are we sure there is no peek-ahead bias?
  - This is particular concern for models using macroeconomic variables
  - Have historical data been adjusted retrospectively?
  - Have data release delays been accounted for?
  - Have differing market trading hours (S&P versus Nikkei) been accounted for?

Research

Identifying Trading Signals

- Demonstrate that a trading signal has predictive power
  - This is often quite hard!
  - A successful backtest alone does not usually convince me
  - Charts can be very useful here



- Robustness checks
  - Do the signals have a directional bias? Should they?
  - Are signals effective after accounting for market trends?
  - Are both the long and short signals profitable?
  - Does a stronger signal have stronger forecasting power? Should it?

Research

Trading Strategy

- Backtesting
  - Drawdowns
  - Performance metrics
  - Persistence (across markets, across subsamples)
- Dependencies
  - Correlations with other strategies
- Robustness
  - Sensitivity to parameters
  - Regime analysis
    - rising/falling interest rates
    - economic growth/recession
    - bull/bear market
- Adding to a broader portfolio
  - Effect on the portfolio's leverage?
  - Effect on the portfolio's risk allocation to assets and asset classes?
  - Effect on the portfolio's volatility/VaR/expected shortfall?

Code Optimisation

Code optimisation by example

- A real-world code-optimisation problem
- The code solved a constrained minimisation problem
- I shall show some of the steps taken to improve the efficiency and reliability of the solver
- A particular concern was to ensure that the solution was not sensitive to the starting point of the minimisation
- Speed was an important consideration here, but was secondary to robustness
- Note: The Parallel Computing Toolbox was not used when producing the following results (although it would probably have sped things up)

Code Optimisation

An Example

This is an optimisation problem that I encountered recently:

Define $\|x\|_2^2 = \sum_i x_i^2$ and $\|x\|_1 = \sum_i |x_i|$, for $x \in \mathbb{R}^n$.

The Problem

$$\begin{aligned} \underset{x}{\text{minimize}} \quad & \|Ax - b\|_2^2 + \lambda\|Cx\|_1, \\ \text{subject to} \quad & \|Dx - e\|_1 \leq f, \end{aligned}$$

where $x \in \mathbb{R}^n$, $A \in \mathbb{R}^{m_a \times n}$, $b \in \mathbb{R}^{m_a}$, $C \in \mathbb{R}^{m_c \times n}$, $D \in \mathbb{R}^{m_d \times n}$, $e \in \mathbb{R}^{m_d}$, $f > 0$, $\lambda > 0$.

The objective function contains a quadratic term and a non-linear term. The constraint is non-linear.

Code Optimisation
First Attempt

- Don’t work harder than you need to!
- Use `fmincon` (Optimization Toolbox)
- Very quick to set up the problem

Code Optimisation

Performance: Naive `fmincon`

- 20 dimensional problem
- 100 different random starting points (not necessarily satisfying constraints)
- Timing = $1,144.92$ seconds
- Objective: mean 2.1152, min 2.0951, max 2.1532

Table: Values for $x_1, \ldots, x_5$.

i	Mean	Min	Max	SD
1	0.2932	0.2559	0.3120	0.0125
2	1.9193	1.7683	2.2189	0.1282
3	-0.7701	-1.5355	-0.2690	0.3528
4	4.5681	4.2161	4.8536	0.1180
5	0.5654	0.4741	0.7047	0.0464

Code Optimisation
Second Attempt

- We like the results from the first attempt
- Can we improve performance or robustness?
- Supply gradients for the objective and constraint using

```
options = optimoptions('fmincon'...
        , 'GradObj', 'on', 'GradConstr', 'on')
```

$$\nabla\left\{\|Dx - e\|_1\right\} = D'\text{sign}(Dx - e)$$

$$\nabla\left\{\|Ax - b\|_2^2 + \lambda\|Cx\|_1\right\} = 2A'Ax - 2A'b + \lambda C'\text{sign}(Cx)$$

- Note: There are many other `fmincon` options that can be changed in the bid to improve performance

Code Optimisation

Performance: `fmincon` with gradients

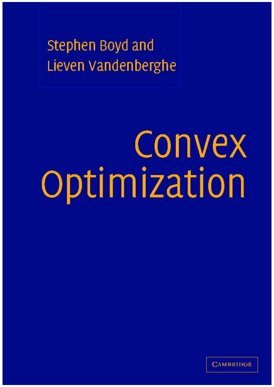
- 20 dimensional problem
- 100 different random starting points (not necessarily satisfying constraints)
- Timing = 96.04 seconds (92.1% speed up)
- Objective: mean 2.1153, min 2.0948, max 2.1865

Table: Values for $x_1, \ldots, x_5$.

i	Mean	Min	Max	SD
1	0.2939	0.2559	0.3128	0.0126
2	1.9119	1.7768	2.2191	0.1255
3	-0.7636	-1.7491	-0.2658	0.3436
4	4.5720	4.2160	4.8536	0.1174
5	0.5659	0.4745	0.7047	0.0447

Code Optimisation

Q. How Can We Improve Further? A. Do Some Research!



- Boyd & Vandenberghe
- Cambridge University Press
- Also available at `http://www.stanford.edu/~boyd/cvxbook/`

Code Optimisation

The Problem Revisited

Find an optimisation problem with the same optimal solution, but with a 'nicer' form:

Equivalent Problem

$$\begin{aligned} \underset{x,u,t}{\text{minimize}} \quad & x'A'Ax - 2A'bx + \lambda \mathbf{1}'t \\ \text{subject to} \quad & -t \preceq Cx \preceq t, \\ & -u \preceq Dx - e \preceq u, \\ & \mathbf{1}'u \leq f, \end{aligned}$$

where $t \in \mathbb{R}_{+}^{m_c}$, $u \in \mathbb{R}_{+}^{m_d}$.

- The objective function is quadratic
- The constraints are linear
- We can use `quadprog` (Optimization Toolbox)

Code Optimisation

Performance: `quadprog`

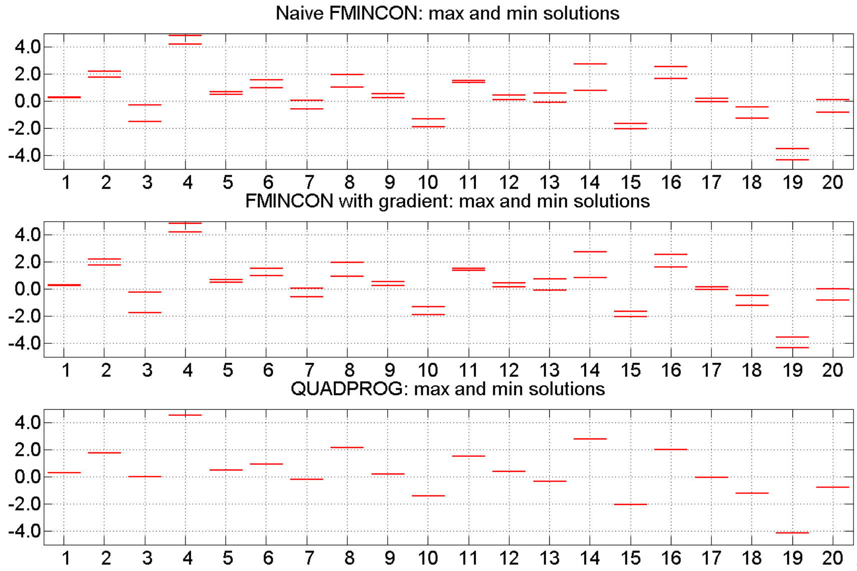
- 20 dimensional problem
- 100 different random starting points (not necessarily satisfying constraints)
- Timing = 1.34 seconds (99.9% speed up)
- Objective: mean 2.0041, min 2.0041, max 2.0041

Table: Values for $x_1, \ldots, x_5$.

i	Mean	Min	Max	SD
1	0.2917	0.2917	0.2917	0.0000
2	1.7458	1.7458	1.7458	0.0000
3	0.0141	0.0141	0.0141	0.0000
4	4.5358	4.5358	4.5358	0.0000
5	0.5095	0.5095	0.5095	0.0000

Code Optimisation

Results: Range of values output for $x_1, \ldots, x_{20}$ after 100 optimisations.



Implementation

Case Study: Challenges Faced

- Not always a distinction between research and production code
  - Code difficult read and poorly commented
  - Scripts calling scripts (variables with unclear scope)
  - ‘If’ conditions in code which are never met
  - No centralised code library or version control
- Multiple data sources
  - Various databases, spread sheets, text files and MAT-files
  - Various update processes
- Strategies running on desktop computers
  - Dependencies on user profiles
  - Potential hardware risk (failing hard drives etc.)
- No API between trading strategies and trade-execution systems

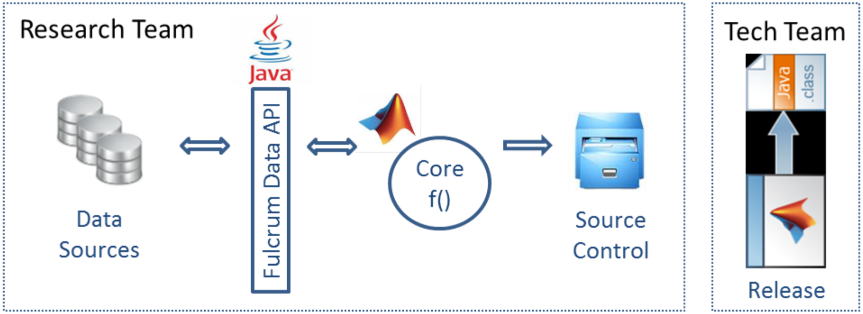
Implementation

Case Study: Writing Production Code

- Write production MATLAB code. Guidelines:
  - Strip down research code to bare bones
  - Remove commented-out code (unless there is a good reason otherwise)
  - Include **useful** comments
  - Use sensible variable names
  - Do not sacrifice readability for performance unless necessary
  - Standardise output
  - Use centralised data source
  - Include links to research (code and documentation)
  - Add to source control
- Export to Java (MATLAB Builder JA)

Implementation

Case Study: Production Code



Implementation

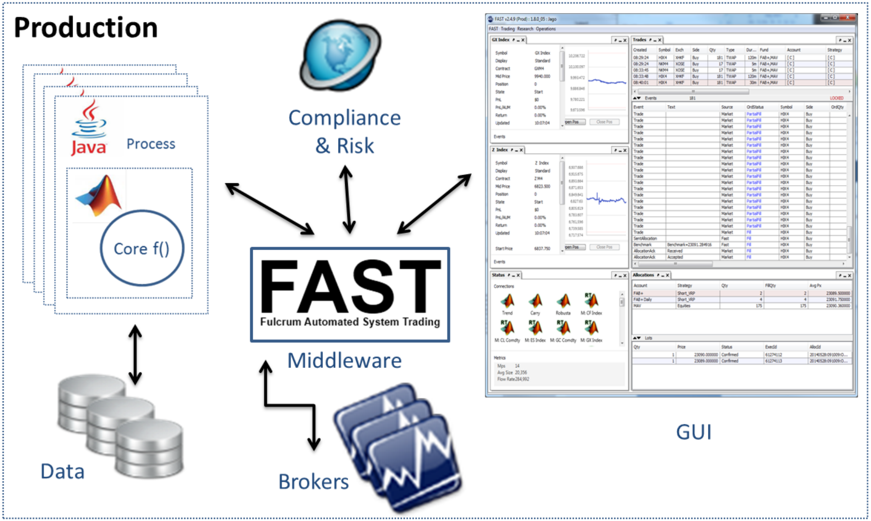
Case Study: Production Environment

Java platform for the execution of medium-frequency trades:

1. Update central database
2. Run MATLAB strategies in parallel
3. Send strategy outputs to MATLAB trade aggregation and sizing routine
4. Display trades in GUI
5. Trades approved by PM using GUI
6. ‘High touch’ trades sent to the traders’ order manager
7. ‘Low touch’ trades sent to the execution order manager
    - Orders are validated using the pre-trade compliance engine
    - Algorithmic execution parameters are determined
    - Orders are routed to the best broker

Implementation

Case Study: Production Environment



FAST v2.4.9 (Prod) : 1.8.0_05 : Jago

FAST Trading Research Operations

GX Index

Symbol	GX Index
Display	Standard
Contract	GXM4
Mid Price	9940.000
Position	0
State	Start
PnL	$0
PnL/AUM	0.00%
Return	0.00%
Updated	10:07:04

Events

Z Index

Symbol	Z Index
Display	Standard
Contract	Z M4
Mid Price	6823.500
Position	0
State	Start
PnL	$0
PnL/AUM	0.00%
Return	0.00%
Updated	10:07:04
Start Price	6837.750

Events

Status

Connections

Metrics

Mps	14
Avg Size	20,356
Flow Rate	284,992

Trades

Created	Symbol	Exch	Side	Qty	Type	Dur...	Fund	Account	Strategy
08:29:24	HIX4	XHKF	Buy	181	TWAP	120m	FAB+,MAV	[C]	[C]
08:29:24	NKM4	XOSE	Buy	17	TWAP	5m	FAB+,MAV	[C]	[C]
08:33:45	NKM4	XOSE	Buy	17	TWAP	5m	FAB+,MAV	[C]	[C]
08:33:48	HIX4	XHKF	Buy	181	TWAP	120m	FAB+,MAV	[C]	[C]
08:40:01	HIX4	XHKF	Buy	181	TWAP	30m	FAB+,MAV	[C]	[C]

Events 181 LOCKED

Event	Text	Source	OrdStatus	Symbol	Side	OrdQty
Trade		Market	PartialFill	HIX4	Buy	
Trade		Market	PartialFill	HIX4	Buy	
Trade		Market	PartialFill	HIX4	Buy	
Trade		Market	PartialFill	HIX4	Buy	
Trade		Market	PartialFill	HIX4	Buy	
Trade		Market	PartialFill	HIX4	Buy	
Trade		Market	PartialFill	HIX4	Buy	
Trade		Market	PartialFill	HIX4	Buy	
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Trade		Market	PartialFill	HIX4	Buy	
Trade		Market	PartialFill	HIX4	Buy	
Trade		Market	PartialFill	HIX4	Buy	
Trade		Market	Fill	HIX4	Buy	
SentAllocation		Fast	Fill	HIX4	Buy	
Benchmark	Benchmark=23091.284916	Fast	Fill	HIX4	Buy	
AllocationAck	Received	Market	Fill	HIX4	Buy	
AllocationAck	Accepted	Market	Fill	HIX4	Buy	

Allocations

Account	Strategy	Qty	FillQty	Avg Px
FAB+	Short_VRP	2	2	23089.500000
FAB+Daily	Short_VRP	4	4	23091.750000
MAV	Equities	175	175	23090.360000

Lots

Qty	Price	Status	ExecId	AllocId
1	23090.000000	Confirmed	61274112	20140528:091009:O...
1	23089.000000	Confirmed	61274113	20140528:091009:O...

MATLAB

Why Use MATLAB in Production?

- Research is done using MATLAB, so we avoid having to rewrite code
  - Facilitates rapid deployment
  - Avoids errors in translation
- Retain access to high-level functions
- Able to run the trading strategies on a desktop using MATLAB for rapid debugging

Note that we are medium-frequency traders

- Low latency is not a requirement for our systems
- We measure run-times in seconds; we are indifferent to the milli, let alone the nano or pico!

MATLAB

Likes

What I like about MATLAB:

- Excellent user interface
- Thoroughly-tested high-level functionality
  - Statistics Toolbox
  - Optimization Toolbox
  - Database Toolbox
  - Datafeed Toolbox
  - Parallel Computing Toolbox
- Multi-paradigm environment (supports scripting, functions, objects, etc.)
- Good documentation
- Technical support