Computational Finance & Economics

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IEEE Technical Committee on Computational Finance and Economics

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What Computational Finance?

- What is Artificial Intelligence?
  - Not easy to define
- Defined by the activities in the community

- Challenging fundamentals in Economics and Finance
  - Rationality
  - Efficient market

- Forecasting and Trading
  - Opportunities, Arbitrage

- Optimization
  - Portfolio optimization

- Understanding markets
  - Automated Bargaining
  - Artificial Markets for
    - Evolving strategies
    - Wind-tunnel testing

Why Computational Finance? What are the challenges ahead?

07 March 2007

Why Computational Finance?

What can be done now:	Enabling technology:
Large scale simulation	Must faster machines
Data warehouse	Much cheaper memory
Building complex models	Agent-technology
Efficient exploration of models	Evolutionary computation (Multi-Obj) Optimisation
Decision support	experimental game theory, constraint satisfaction

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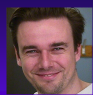


Forecasting

Is the market predictable?
What exactly is the forecasting problem?

EDDIE adds value to user input

- User inputs *indicators*
  - e.g. moving average, volatility, predications
- EDDIE makes *selectors*
  - e.g. "50 days moving average > 89.76"
- EDDIE combines selectors into *trees*
  - by discovering interactions between selectors
- Finding thresholds (e.g. 89.76) and interactions by human experts is laborious

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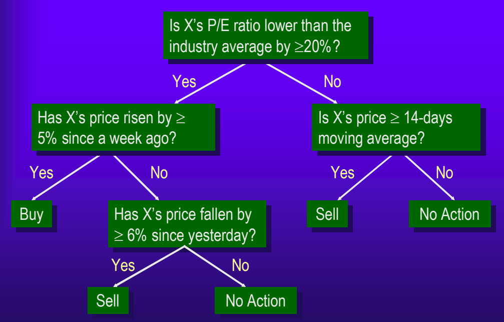
An Example Decision Tree



Syntax of GDTs in EDDIE-2

<Tree> ::= "If-then-else" <Condition> <Tree> <Tree> | Decision
<Condition> ::= <Condition> "And" <Condition> |
<Condition> "Or" <Condition> |
"Not" <Condition> |
Variable <RelationOperation> Threshold
<RelationOperation> ::= ">" | "<" | "="

Variable is an indicator / feature
Decision is an integer, "Positive" or "Negative" implemented
Threshold is a real number

- Richer language ⇒ larger search space

A taste of user input

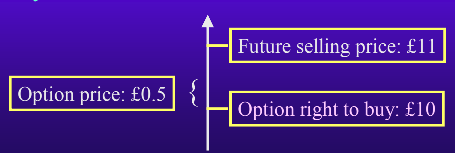
Given	Expert adds:	More input:		Define target:
Daily closing	50 days m.a.	Volat-ility	…..	↑4% in 21 days?
90	80	50		1
99	82	52		0
87	83	53		1
82	82	51		1
…..	…..	…..		…..

Our EDDIE/FGP Experience

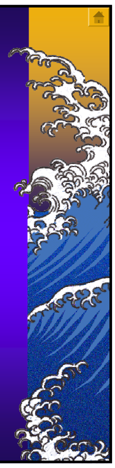
- Patterns exist
  - Would they repeat themselves in the future?
    (EMH debated for decades)
- EDDIE has found patterns
  - Not in every series
    (we don't need to invest in every index / share)
- EDDIE extending user's capability
  - and give its user an edge over investors of the same caliber

Arbitrage Opportunities

- Futures are obligations to buy or sell at certain prices
- Options are rights to buy at a certain price
- If they are not aligned, one can make risk-free profits
  - Such opportunities should not exist
  - But they do in London

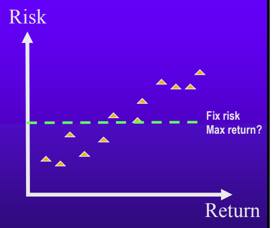


Portfolio Optimization



Portfolio Optimization

- Typically:
  - High risk → high return
  - Diversification reduces risk
- Task: find a portfolio
  - Maximize return, minimize risk
- Difficulty: constraints, e.g.
  - No more than *n* stocks
  - Not too much on one stock
  - Not too much on one sector
- Optimization problem
  - Note: how to measure risk?



Automated Bargaining

Automatic Bargaining Overview

n shared variables

Cost ?? *Utility*

Supplier | Supplier | Supplier

Supply price defines my cost

- Maximize profit
- Satisfy constraints
  - purchase
  - sell
  - schedule

Customer | Customer | Customer

Who do I know?

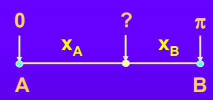
Motivation in e-commerce: talk to many

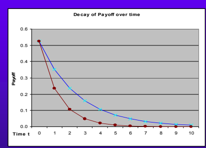
How to bargain?
Aim: to agree on price, delivery time, etc.
Constraint: deadlines, capacity, etc.
Who to serve? Who to talk to next?

Bargaining in Game Theory

- Rubinstein Model:

In reality:
Offer at time $t = f(r_A, r_B, t)$
Is it necessary?
Is it rational? (What *is* rational?)





- A's payoff x_A drops as time goes by
  A's Payoff = $x_A \exp(-r_A t\Delta)$
- Important Assumptions:
  - Both players rational
  - Both players know *everything*
- Equilibrium solution for A:
  $\mu_A = (1 - \delta_B) / (1 - \delta_A \delta_B)$
  where $\delta_i = \exp(-r_i \Delta)$

Optimal offer: $x_A = \mu_A$ at t=0

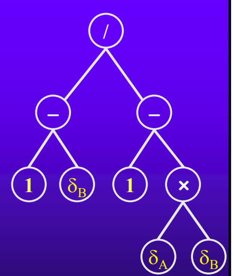
Notice: No time *t* here

Evolutionary Rubinstein Bargaining, Overview

- Game theorists solved Rubinstein bargaining problem
  - Subgame Perfect Equilibrium (SPE)
- Slight alterations to problem lead to different solutions
  - Asymmetric / incomplete information
  - Outside option
- Evolutionary computation
  - Succeeded in solving a wide range of problems
  - EC has found SPE in Rubinstein's problem
  - Can EC find solutions close to unknown SPE?
- Co-evolution is an *alternative approximation* method to find game theoretical solutions
  - Less time for approximate SPEs
  - Less modifications for new problems

Issues Addressed in EC for Bargaining

- Representation
  - Should *t* be in the language?
- One or two population?
- How to evaluate fitness
  - Fixed or relative fitness?
- How to contain search space?
- Discourage irrational strategies:
  - Ask for $x_A > 1$?
  - Ask for more over time?
  - Ask for more when δ_A is low?



Representation of Strategies

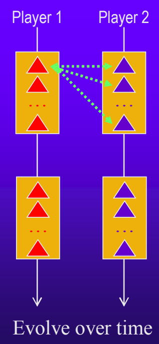
- A tree represents a mathematical function g
- Terminal set: {1, δ_A, δ_B}
- Functional set: {+, −, ×, ÷}
- Given g, player with discount rate r plays at time t

$$g \times (1 - r)^t$$

- Language can be enriched:
  - Could have included e or time t to terminal set
  - Could have included power ^ to function set
- Richer language → larger search space → harder search problem

Two populations – co-evolution

- We want to deal with asymmetric games
  - E.g. two players may have different information
- One population for training each player's strategies
- Co-evolution, using relative fitness
  - Alternative: use absolute fitness



Incentive Method: Constrained Fitness Function

- No magic in evolutionary computation
  - Larger search space → less chance to succeed
- Constraints are heuristics to focus a search
  - Focus on space where promising solutions may lie
- Incentives for the following properties in the function returned:
  - The function returns a value in (0, 1)
  - Everything else being equal, lower δ_A → smaller share
  - Everything else being equal, lower δ_B → larger share

  Note: this is the key to our search effectiveness

Models with known equilibriums

Complete Information
- Rubinstein 82 model:
  - Alternative offering, both A and B know δ_A & δ_B
- Evolved solutions approximates theoretical
- Working on a model with outside option

Incomplete Information
- Rubinstein 85 model:
  - B knows δ_A & δ_B
  - A knows δ_A and δ_B^{weak} & δ_B^{strong} with probability Ω_{weak}
- Evolved solutions approximates theoretical

Models with unknown equilibriums

- Modified Rubinstein 85 models
- Incomplete knowledge
  - B knows δ_B but not δ_A; A knows δ_A but not δ_B
- Asymmetric knowledge
  - B knows δ_A & δ_B; A knows δ_A but not δ_B
- Asymmetric, limited knowledge
  - B knows δ_A & δ_B
  - A knows δ_A and a normal distribution of δ_B
- Working on limited knowledge, outside option
- Future work: new bargaining procedures

Evolutionary Bargaining, Conclusions

- Demonstrated GP's flexibility
  - Models with known and unknown solutions
  - Outside option
  - Incomplete, asymmetric and limited information
- Co-evolution is an *alternative approximation* method to find game theoretical solutions
  - Relatively quick for approximate solutions
  - Relatively easy to modify for new models
- Genetic Programming with incentive / constraints
  - Constraints used to focus the search in promising spaces

Artificial Market

Markets are efficient in the long run

How does the market become efficient?

Do all agents converge in their opinions?

Wind-tunnel testing for new markets

Evolving Agents

Should agents adapt to the environment?

Co-evolution

The Red Queen Thesis

In this place it takes all the running you can do, to keep in the same place.

- Chen & Yeh:
  - Endogenous prices
  - Agents are GPs
  - "Peer pressure" (relative wealth) lead to agents retraining themselves
  - Retraining is done by "visiting the business school"
- Markose, Martinez & Tsang:
  - CCFEA work in progress
  - Wealth exhibits Power Law
  - Wealth drives retraining
  - Retraining is done by EDDIE

Evolving Agents

- Sunders, Cliff:
  - Zero intelligence agents
  - Market efficiency can be obtained by zero-intelligence agents as long as the market rules are properly set.
  - This result challenges the neoclassical models regarding the utility maximization behaviour of economic agents
- Schulenburg & Ross
  - Heterogenous agents (agents may have different knowledge)
  - Agents modelled by classifier systems
  - Exogenous prices
  - Beat buy-and-hold, trend follower and random walk agents

Conclusions
Computational Finance & Economics

- Computing has changed the landscape of finance and economics research
  - We can do what we couldn't in the past
- Evolutionary computation plays major roles in
  - Forecasting investment opportunities
  - Approximating subgame equilibrium in bargaining
  - Understanding markets
  - Wind-tunnel testing new market mechanism

Questions & Comments?

Edward Tsang

http://www.cfea-labs.net

http://cswww.essex.ac.uk/CSP/finance

http://cswww.essex.ac.uk/CSP/edward

Supplementary Information

Joseph Stiglitz

- Nobel Economic Prize 2001
- Senior VP and Chief Economist, World Bank, 1997-2000
- Critical view on globalization
- Founder, The Initiative for Policy Dialogue, to:
  - Explore policy alternatives
  - Enable wider civic participation in economic policymaking

Future of Computational Finance

Opportunities and Challenges in CF&E

- Wide varieties of financial applications
- Different types of learning mechanism
- Different markets to simulate
- Wind-tunnel tests will become the norm
  - Yet to be developed
- Challenges:
  - Large number of parameters to tune
  - What can the simulations tell us?

The Computational Finance Community

- Conferences:
  - IEEE International Conference on Computational Ineelligence for Financial Engineering
  - Annual Workshop on Economics with Heterogenous Interacting Agents (WEHIA 2005 at Essex, Markose, Sunders, Dempster)
  - International Conference on Computing in Economics and Finance
  - International Joint Conference on Autonomous Agents and Multi-Agent Systems
- Useful web sites:
  - Tesfatsion's Agent-based Computational Economics
  - Chen's AI-ECON Research Centre
- IEEE Network on Computational Finance and Economic
- IEEE Technical Committee on Computational Finance and Economics

Rationality

Rationality is the assumption behind many economic theories

What does being rational mean?

Are we rational?

The CIDER Theory

What is Rationality?

- Are we all logical?
- What if ***Computation*** is involved?
- Does ***Consequential Closure*** hold?
  - If we know P is true and P → Q, then we know Q is true
  - We know all the rules in Chess, but not the optimal moves
- "Rationality" depends on computation power!
  - Think faster → "more rational"

"Bounded Rationality"

CIDER: Computational Intelligence Determines Effective Rationality (1)

- You have a product to sell.
- One customer offers £10
- Another offers £20
- Who should you sell to?

- Obvious choice for a rational seller

CIDER: Computational Intelligence Determines Effective Rationality (2)

- You are offered two choices:
  - to pay £100 now, or
  - to pay £10 per month for 12 months
- Given cost of capital, and basic mathematical training
- Not a difficult choice



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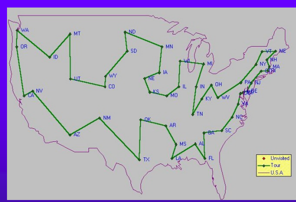
CIDER: Computational Intelligence Determines Effective Rationality (3)

- Task:
  - You need to visit 50 customers.
  - You want to minimize travelling cost.
  - Customers have different time availability.
- In what order should you visit them?



- This is a very hard problem
- Some could make wiser decisions than others

"Bounded Rationality"

- Herbert Simon:
  - Most people are only partly rational, and are in fact emotional/irrational in part of their actions
- "Boundedly" rational agents behave in a manner that is nearly as optimal with respect to its goals as its resources will allow
  - Resources include processing power, algorithm and time available
- Quantifiable definition needed?

Efficient Market Hypothesis

- Financial assets (e.g. shares) pricing:
  - All available information is fully reflected in current prices
- If EMH holds, forecasting is impossible
  - Random walk hypothesis
- Assumptions:
  - Efficient markets (one can buy/sell quickly)
  - Perfect information flow
  - Rational traders

Does the EMH Hold?

- It holds for the long term
- "*Fat Tail*" observation:
  - big changes today often followed by big changes (either + or –) tomorrow
- How fast can one adjust asset prices given a new piece of information?
  - Faster machines certainly help
  - So should faster algorithms (CIDER)

Test: Syntax – GDTs in EDDIE-2

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Variable is an indicator / feature
Decision is an integer, "Positive" or "Negative" implemented
Threshold is a real number

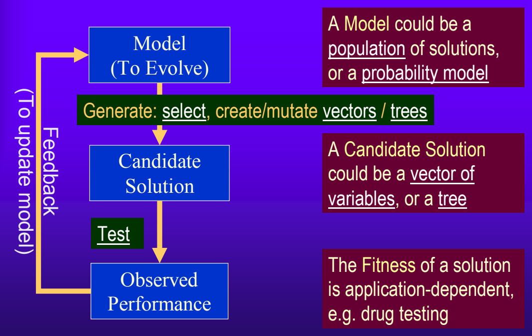
- Richer language ⇒ larger search space

CCFEA Centre for Computational Finance and Economic Agents 2005-06

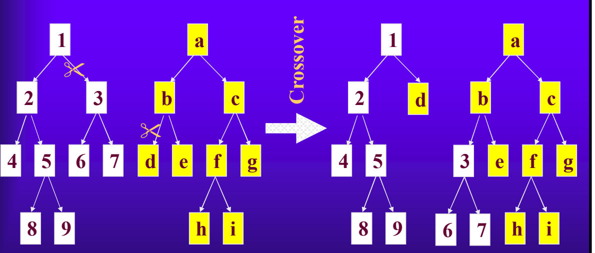
- Economics
  - Sheri Markose
  - Dietmar Maringer
  - Kyriakos Chourdakis
  - Abhinay Muthoo
- Computer Science
  - Edward Tsang
  - Qingfu Zhang
  - John Gan, Maria Fasli, Riccardo Poli
- Administrators:
  - Lynda Triolo
  - Julie Peirson
- Students:
  - ~ 30 PhD +Master
- City Associates
  - HSBC, Barclays, Old Mutual, etc.

http://www.essex.ac.uk/ccfea

Evolutionary Computation: Model-based Generate & Test

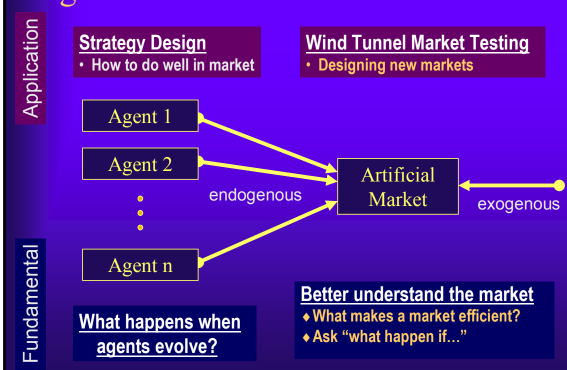


GP Operators



Mutation: change a branch

Agent-based Artificial Market



Wind-tunnel tests for new markets

- New markets are being invented
  - e-Bay, electricity, roads
- Model new markets to check if they work
  - Answer what-if questions
  - Evolve agents to approximate equilibriums

Red Queen

… Now, *here*, you see, it takes all the running *you* can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that! …

The Collaborator Problem

Research Agenda:

To define for management a mechanism to achieve all-win solutions

Agent-based Payment Card Market Model