Selecting Simulation Algorithm Portfolios by Genetic Algorithms

Roland Ewald     René Schulz     Adelinde M. Uhrmacher
JAMES II

- Java framework for modeling & simulation
- Open source (http://www.jamesii.org)
- Focus on extensibility and flexibility
- Over 500 plug-ins, combinable
Simulation Algorithms in JAMES II

Plug-in type
Simulator

Plug-in type
EventQueue

Algorithm Combinations

In the following: algorithms.
Simulation Algorithm Selection in JAMES II

Which simulation algorithm to select for a given problem?

⇒ Algorithm Selection Problem [Rice, 1976]
Simulation Algorithm Selection in JAMES II

Dozens to hundreds of "algorithms" available!
Adaptive Replication

- Restricted to Stochastic Simulation
- *Policies* to solve the Multi-Armed Bandit Problem
- Requires **sufficiently many replications** [Ewald *et al.*, 2009]
How many replications are ’sufficient’?

- Previous study: 1,000 replications
- More options ⇒ slower convergence
Improving Convergence Speed

Solution Strategies:

- Better policies → exploration vs. exploitation
- Reduce number of options
Improving Convergence Speed

Solution Strategies:

- Better policies $\rightarrow$ exploration vs. exploitation
- Reduce number of options

Portfolio Selection

- Given some assets $\mathbb{A} = \{a_1, \ldots, a_n\}$
- What subset $A \subseteq \mathbb{A}$ of assets is the most beneficial?
- Requires additional data
Portfolio Theory

Finance

- Asset Price $\rightarrow$ Random Variable
- Portfolios for capital allocation: $\alpha = (\alpha_1, \ldots, \alpha_n) \in [0, 1]^n$
- $\sum \alpha_i = 1$
- Additional constraints: size, zero-risk assets
Mean-Variance Portfolios

Finance
- Asset Price → Random Variable
- Portfolios for capital allocation: \( \alpha = (\alpha_1, \ldots, \alpha_n) \in [0, 1]^n \)
- \( \sum \alpha_i = 1 \)

Efficient Frontier

Optimization Problem (cf. [Markowitz, 1952]):

\[
f(\alpha) = \lambda \left( \sum_{i=1}^{n} \alpha_i \cdot \hat{R}_i \right) - (1 - \lambda) \left( \sum_{i=1}^{n} \sum_{j=1}^{n} \alpha_i \cdot \alpha_j \cdot \hat{\sigma}_{i,j} \right)
\]
Portfolio Theory → Algorithm Portfolios

**Computer Science**

- Asset Prices ⇒ Algorithm Performances
- $\alpha_i$ allocate CPU time (e.g. $\in \{0.0, 0.1, \ldots, 1\}$)
- Additional constraints: size, execution scheme

---

![Bar charts for Problem A and Problem B](chart.png)

Problem A
- Execution Time
- Sim. #1
- Sim. #2
- Sim. #3

Problem B
- Execution Time
- Sim. #1
- Sim. #2
- Sim. #3
Simulation Algorithm Portfolios

Differences to other applications (e.g. [Gomes & Selman, 2001]):

- Problems easier than NP
- No phase transitions or search heuristics
- Specific requirements: time constraints, replications, etc.
Simulation Algorithm Portfolios

Differences to other applications (e.g. [Gomes & Selman, 2001]):
- Problems easier than NP
- No phase transitions or search heuristics
- Specific requirements: time constraints, replications, etc.

Applications:
- **Adaptive Replication**
- Brute-force parallelization
- Performance analysis
Requirements

- Constraints: portfolio size, permissible values for the $\alpha_i$
- Multiple performance metrics (accuracy, execution time)
- Speed: portfolio selection at runtime
- Objective function may depend on application
Requirements

- Constraints: portfolio size, permissible values for the $\alpha_i$
- Multiple performance metrics (accuracy, execution time)
- Speed: portfolio selection at runtime
- Objective function may depend on application

**Constraints make optimization problem hard!**
$\Rightarrow$ **Use meta-heuristics!** (e.g. [Wilding, 2003])
Portfolio Selection with GA

General Procedure:

1. Retrieve performance data
2. Select portfolio
3. Start adaptive replication

Diagram:
- Performance Data
- Portfolio Selection (e.g.: GA)
  - Simulation Algorithms: Mutation, Selection, Recombination
  - Generation i
  - Generation i+1
  - Selected Portfolio
  - New Simulation Problem
  - Adaptive Replication

ADS Workshop, May 17, 2010
UNIVERSITY OF ROSTOCK | FACULTY OF COMPUTER SCIENCE AND ELECTRICAL ENGINEERING
Portfolio Selection with GA

- **Return**: average execution time (minimization!)
- **Risk**: adaptation fails
Portfolio Selection with GA

- **Return**: average execution time (minimization!)
- **Risk**: adaptation fails

**Fitness Function for Adaptive Replication**

\[
f(\alpha) = \lambda \sum_{i=1}^{n} \frac{\min\{p_{i,j}\mid \alpha_j \neq 0\}}{n} + (1 - \lambda)\bar{p}(\alpha)
\]

- \(p_{i,j}\) – performance of algorithm \(j\) on problem \(i\)
- \(\bar{p}(\alpha)\) – average performance of portfolio on all problems
Evaluation with Hypothetical Setups

- Stochastic elements (portfolio selection, policies, algorithms)
- Evaluation under various (controlled) circumstances
- More details: see paper

Problem #1 (Class #1)  
Probability  
Hypothetical Algorithm Cluster #1 … #2 …

Problem #2 (Class #2)  
Hypothetical Execution Time

Performance Data Samples
“On average, a single simulation run takes $\approx 21.5$ s when using the UCB2 policy to execute 200 replications, choosing from 250 algorithms with GA-selected portfolio.”

$\Rightarrow$ Portfolio selection parameters: size $\in [3, 6]$, $\lambda = 1$ (risky)
Results

Average Execution Time per Replication (in s)

- **Risky Portfolio Selection with GA** ($\lambda = 1.0$)
- **Safe Portfolio Selection with GA** ($\lambda = 0.0$)

**Graph:**
- **ED**
- **P**
- **Random**
- **UCB2**
Further Results

- Heavy-tailed runtime distributions do not affect results
- Speed-up in small yet realistic scenario
- Less replications suffice (not in paper)
Bottom Line?
Overview: Algorithm Selection in JAMES II

Stochastic Simulation

- Multi-Armed Bandit Policies

Data

+ Portfolios

Features + Data

Prediction (e.g. Data Mining)

Simulation Algorithm Selection
Summary & Outlook

- **Simulation Algorithm Portfolios**
- **Useful** for adaptive replication
- **Interdependence:** Portfolio Approach $\iff$ Replication Policy $\iff$ Problem

- How to collect enough performance data?
- How does GA-based selection compare to other techniques?
- How to integrate portfolio selection into the JAMES II GUI?
Thank you.

Questions?

Download JAMES II from
http://www.jamesii.org
References

Ewald, Roland, Leye, Stefan, & Uhrmacher, Adelinde M. 2009.
An Efficient and Adaptive Mechanism for Parallel Simulation Replication.
*Pages 104–113 of: Proc. of the 23rd Workshop on Principles of Advanced and Distributed Simulation.*
IEEE Computer Society.

Gomes, Carla P., & Selman, Bart. 2001.
Algorithm portfolios.
*Artificial Intelligence,* 126(1-2), 43–62.

Markowitz, Harry. 1952.
Portfolio Selection.

The Algorithm Selection Problem.
*Advances in Computers,* 15, 65–118.

Using genetic algorithms to construct portfolios.
*Chap. 6, pages 135–160 of: Satchell, Stephen, & Scowcroft, Alan (eds), Advances in Portfolio Construction and Implementation.*
Quantitative Finance Series.