A Novel Learning Algorithm based on a Multi-Agent Structure for Solving Multi-Mode Resource-Constrained Project Scheduling Problem

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Problem Description (1/4)

- Resource Constrained Project Scheduling Problem (RCPSP)
  - Scheduling to satisfy an/multi objective(s)
    - Resource Requirements
    - Precedence Relations
- Multi-Mode Resource-Constrained Project Scheduling Problem (MMRCPSP)
- An NP-hard Optimization Problem [1]

[1] Blazewicz, J., Lenstra, JK.,Kan, AHGR.,1983. Scheduling subject to resource constraints: Classification and complexity. Discrete Appl Math 5: 11–24.

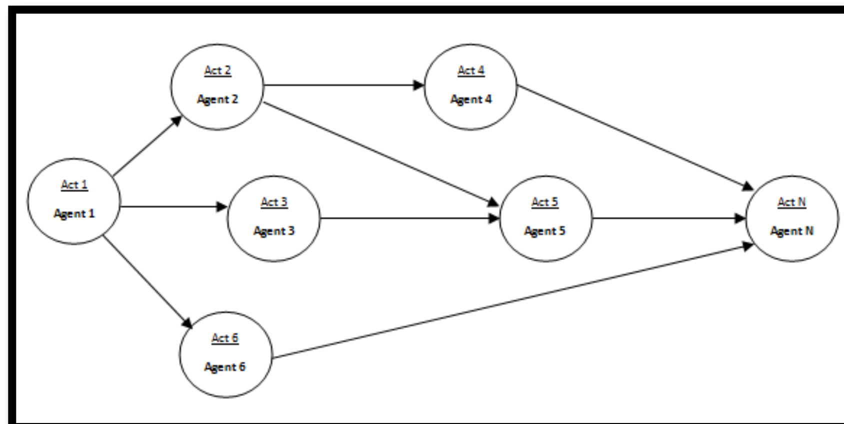
Problem Description (2/4)

- Resource Requirements [1]:
  - **Renewable** (e.g. manpower, machines and space)
    - Available on a period-by-period basis
  - **Nonrenewable** (e.g. money, energy and raw material)
    - Limited on a total project basis
  - **Doubly Constrained** (e.g. money and manpower)
    - Limited on total project basis as well as on per-period basis

[1] Slowinski, R., Soniewicki, B., Weglarz, J., 1994. DSS for multiobjective project scheduling. European Journal of Operational Research 79, 220–229.

Problem Description (3/4)

- Precedence Relations:
  - Activity-On-Node (AON) Network/Diagram
    - Nodes → Activities
    - Arcs → Precedence Relations



  - Activity-On-Arc Network
    - Node → Events
    - Arcs → Activities

Problem Description (4/4)

- Schedule Generation Scheme:
  - Serial SGS
    - n iterations
    - Only one eligible activity can be selected at each iteration
    - Selection is based on precedence and resource constraints
    - Activity Oriented
  - Parallel SGS
    - At most n iterations
    - Several eligible activities can be scheduled
    - A time is associated with each iteration
    - The associated time equals the minimum finishing time of the activities scheduled during the previous stages
    - Time Oriented

Applications (1/2)

- **Project Management**
  - Crew Scheduling [1]
  - Fleet Management [2]
  - Machine Assignment [2]
  - Emergency Equipment/ Personnel Management

[1] Chang, S. C. 2002. A new aircrew-scheduling model for short-haul routes. Journal of Air Transport Management, 8(4), 249–260.
[2] Topaloglu, H., Powell, Warren B., 2005. A Distributed Decision Making Structure for Dynamic Resource Allocation Using Nonlinear Functional Approximations. Operations Research, Volume 53, Issue 2.

Applications (2/2)

- **Industry**
  - Construction Engineering (Automobile Industry) [1]
  - Software Development [1]
  - Make-to-Order Companies [1]
- **Other Optimization Problems**
  - Bin Packing [2]
  - Knapsack Problem [2]
  - Wireless Sensor Networks

[1] Brucker, P., Drexl, A., Möhring, R., Neumann, K., Pesch, E., 1999. Resource-constrained project scheduling: Notation, classification, models, and methods. European Journal of Operational Research, 112 (1), pp. 3-41.
[2] Hartmann, S., Briskorn, D., 2010.A survey of variants and extensions of the resource-constrained project scheduling problem. European Journal of Operational Research, 207 (1), pp. 1-14.

Literature Review

- Exact Algorithms
- Heuristic Algorithms
  - Classical Metaheuristics
    - Genetic Algorithm (GA)
    - Tabu Search (TS)
    - Simulated Annealing (SA)
    - Ant Colony (AC)
    - Bee Colony (BC)
  - Non-Standard Metaheuristics
    - Local search-oriented approaches
    - Population-based approaches
- Agent-based Algorithms

Problem Assumptions

- Interruption
  - An activity may be interrupted.
- Parameters
  - All the parameters are assumed to be nonnegative and integer valued.
- Preemption
  - Preemption is not allowed.
- Resources
  - Renewable
  - Nonrenewable
- Objective
  - Minimization of project makespan

Problem Formulation

- A project has N activities:
  - a_1 , a_2 , a_3 , … , a_N
- Each activity can be performed in one out of a set of K modes:
  - m_{i1} , m_{i2} , m_{i3} , … , m_{ik}
- Each mode corresponds to a specific:
  - Activity Duration: d_{mij}
  - Resource Requirements: ren_{mij} , $nren_{mij}$
- An activity i has a set of activities as its predecessors: P_i
- It also has a set of activities as its successors: S_i

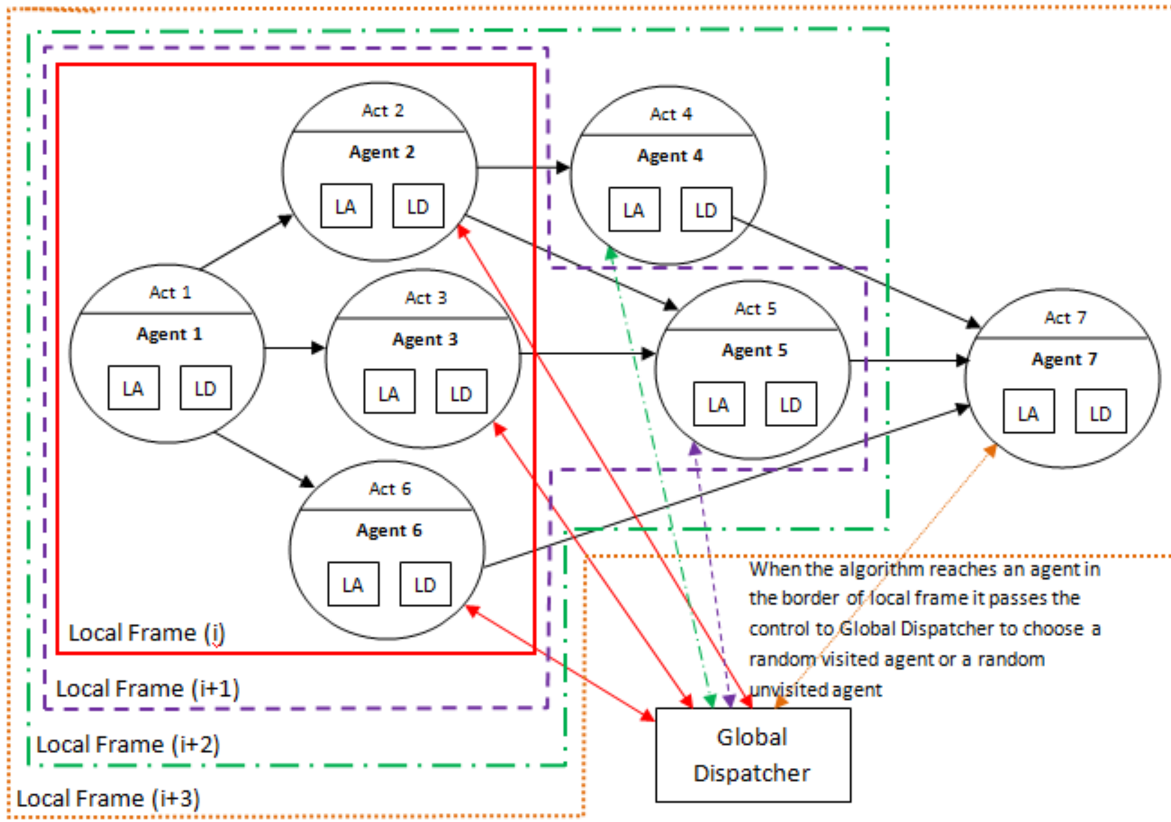
$$min \sum_{i=1}^{n} d_i = min \sum_{j=1}^{K} m_{ij} d_{m_{ij}} \qquad i = 1, 2, 3, \dots, N$$

The Proposed Algorithm (1/3)

- Incorporating Agent Technology:
  - An agent is assigned to each activity on AON network (Multi Agent System)
- Learning Automata (rationality)
  - Order of visiting the successor activities
  - Mode Selection
- Dispatchers (randomness)
  - Local
  - Global
- Reinforcement Learning
  - Partially made schedule's makespans
- Local Frame

The Proposed Algorithm (2/3)

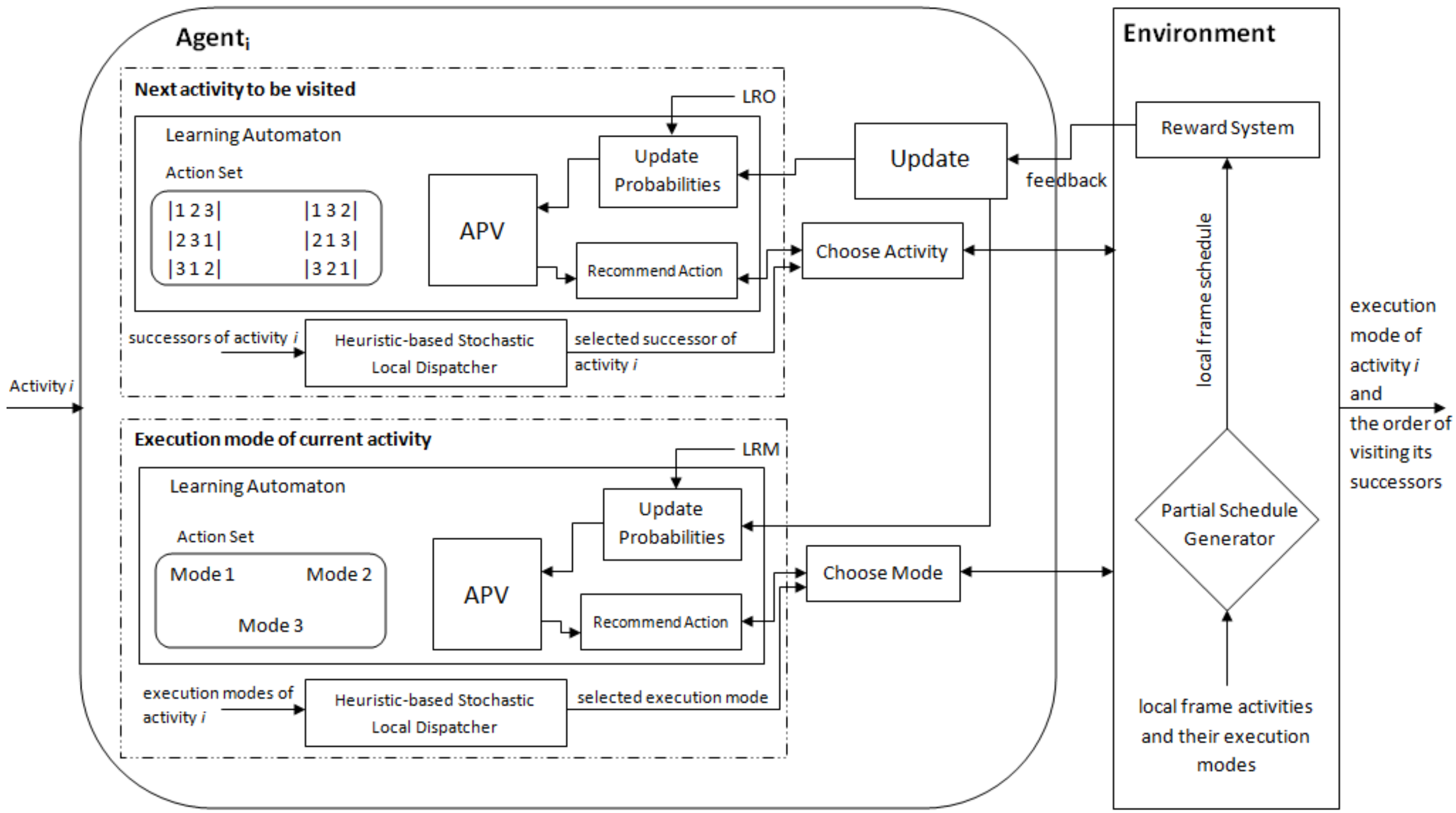
- Construction of local frames



$$h_{i,j} = \frac{1}{D_{i,j} \times RR_{i,j}} \qquad i = 1,2,\ldots, Successors, j = 1,2,\ldots, Execution\ Modes\ of\ Activity\ i$$

The Proposed Algorithm (3/3)

- Inner structure of each agent



Experimental Results (1/5)

- **Simulations:**
  - MATLAB 2009
  - Intel(R) Core(TM)2 Duo processor
  - 4GB RAM
  - 64-bit windows 7 operating system
- **Benchmark:**
  - RCPSP Library: http://129.187.106.231/psplib/
- **Parameters:**
  - LRO = LRM = 0.4
  - r_{eq} = 0.01
  - iterations = 3

Experimental Results (2/5)

- MMRCPSP

Table 1. Average Computation Times

Algorithm	SGS	c15	c21	j10	j12	j18	j20	j30	m1	m5	n3	r4
		10_1	31_2	61_7	31_10	30_9	24_5	49_7	57_1	21_4	54_10	39_3
CPSO [8]	Serial	7.57	16.38	6.15	8.44	17.94	16.34	31.09	4.52	13.33	18.24	17.92
HGA [11]	Both	10.23	18.86	9.05	10.43	19.49	18.46	34.07	7.32	16.31	21.03	20.12
MARLA [17]	Serial	1.29	2.09	0.80	1.21	2.22	2.43	5.15	1.65	1.79	3.01	1.99
MALA [proposed]	Serial	1.59	3.01	0.86	1.26	3.10	4.11	16.56	2.38	2.60	4.15	3.56

Experimental Results (3/5)

- MMRCPSP

Table 2. Distribution of the Computation Times (%) – Dataset = j10

Algorithm	SGS	[0.1,0.3)	[0.3,0.5)	[0.5,0.7)	[0.7,1)	[1,3)	[3,5)	[5,7)	[7,9)	[9,12]
CPSO [8]	Serial	0	0	0	0	0	52.38	23.80	19.04	4.78
HGA [11]	Both	0	0	0	0	0	0	28.57	66.66	4.77
MARLA [17]	Serial	0	0	4.76	95.24	0	0	0	0	0
MALA [proposed]	Serial	0	0	28.57	71.43	0	0	0	0	0

Experimental Results (4/5)

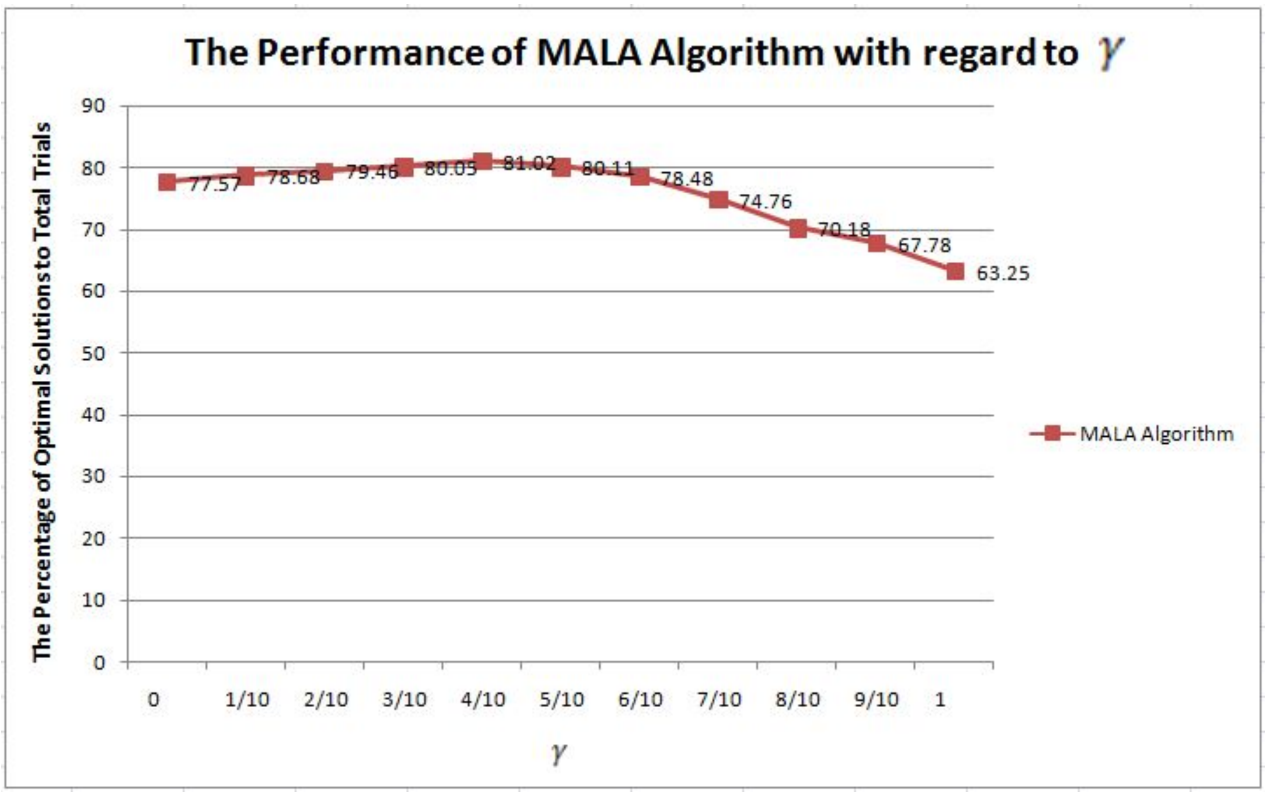
- MMRCPSP

Table 3. Comparison of Proficiency in Different Algorithms

Algorithm	SGS	j10			j12			j16			j18			j20		
		Opt. (%)	Avg. Dev. (%)	Max. Dev. (%)	Opt. (%)	Avg. Dev. (%)	Max. Dev. (%)	Opt. (%)	Avg. Dev. (%)	Max. Dev. (%)	Opt. (%)	Avg. Dev. (%)	Max. Dev. (%)	Opt. (%)	Avg. Dev. (%)	Max. Dev. (%)
CPSO [8]	Serial	99.25	0.03	0.05	98.47	0.09	0.12	85.91	0.44	0.47	79.89	0.89	0.92	74.19	1.10	1.13
HGA [11]	Both	98.51	0.06	0.09	96.53	0.17	0.19	90.00	0.41	0.44	84.96	0.63	0.65	80.32	0.87	0.91
MARLA [17]	Serial	98.70	0.05	0.06	98.17	0.10	0.13	92.18	0.24	0.26	86.23	0.21	0.23	81.59	0.85	0.88
MALA [proposed]	Serial	98.73	0.05	0.06	98.25	0.09	0.11	92.31	0.22	0.24	86.42	0.18	0.20	81.71	0.80	0.83

Experimental Results (5/5)

- MMRCPSP



Conclusion

- **Problem**
  - Multi-Mode Resource-Constrained Project Scheduling Problem
- **Solution**
  - A Novel Distributed Multi-Agent Solution
  - Learning Automata (rational decisions)
  - Dispatchers (random decisions)
  - Local Frame
  - Incorporation of Reinforcement Learning using Partially Made Schedules
- **Simulations**
  - MATLAB 2009
- **Benchmark**
  - PSPLIB Library
- **Results**

Future Works

- Agents coordination
- Better heuristic values
- Noise tolerance

Questions

Thanks For Your Attention!