Building a Distributed Genetic Algorithm with the Jini Network Technology

Brian Zorman

(Gregory M. Kapfhammer and Robert Roos)

Sixth Annual Jini Community Meeting

Boston • June 17-20, 2002

Problem Analysis

- Genetic Algorithms:
  - **Pros:** robust and efficient
  - **Cons:** execution cost and Quality of Solution (QoS)

- Possible solution: how can we harness the benefits of distributed computing frameworks?

- Can we reduce cost of execution and improve quality of solution with a distributed genetic algorithm (DGA)?

Allegheny College
Department of Computer Science

Bridging the Gap: Distributed Genetic Algorithms

Punctuated Equilibrium

Genetic Algorithms:

1.) Execution cost

2.) Lack of diversity

Distributed Systems:

1.) Resource Sharing

2.) Concurrency

3.) Scalability

4.) Openness

Allegheny College
Department of Computer Science

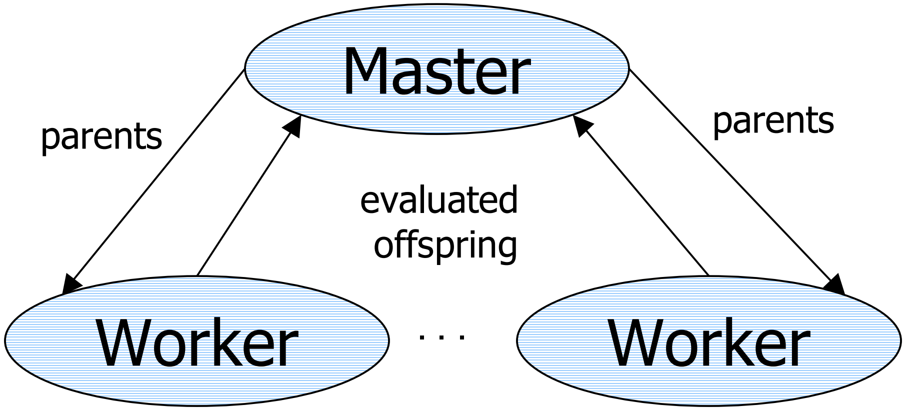
Exploring Punctuated Equilibrium

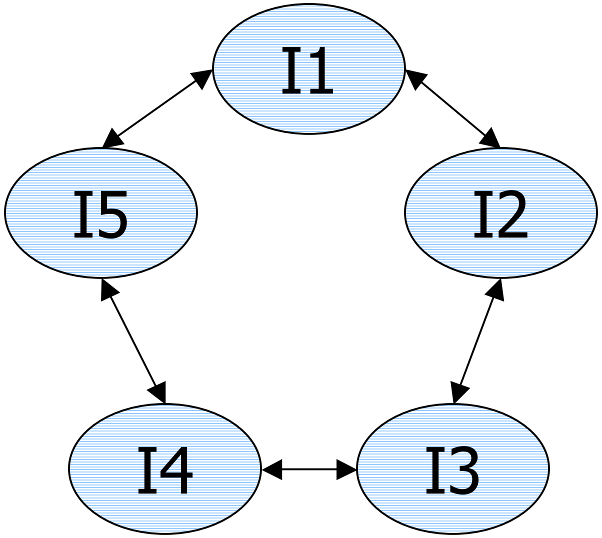
- The theory of punctuated equilibrium:
  - An isolated environment can reach a point of stability
  - The injection of new individuals could cause rapid evolution
- Could we design a distributed system to simulate this theory?
- How can the Jini network technology and the JavaSpaces object repository help us to build this distributed system?

Allegheny College
Department of Computer Science

Designing the Models

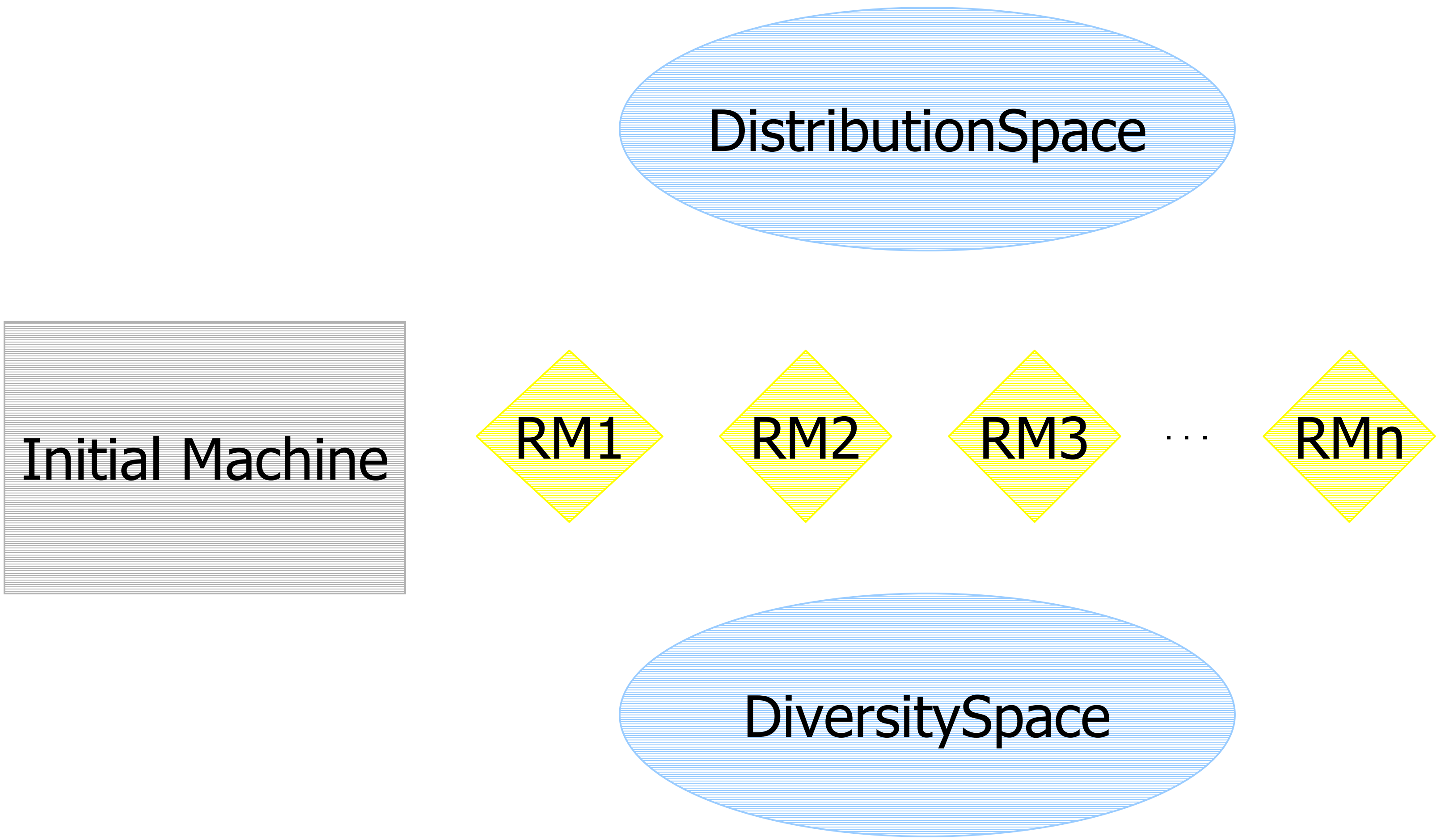
- Examined two popular models: **master-worker** and **island**
- Chose combination of master-worker and island models
  - **Master-worker:** parallel execution and simplicity
  - **Island model (punctuated equilibrium):** parallel execution and additional diversity



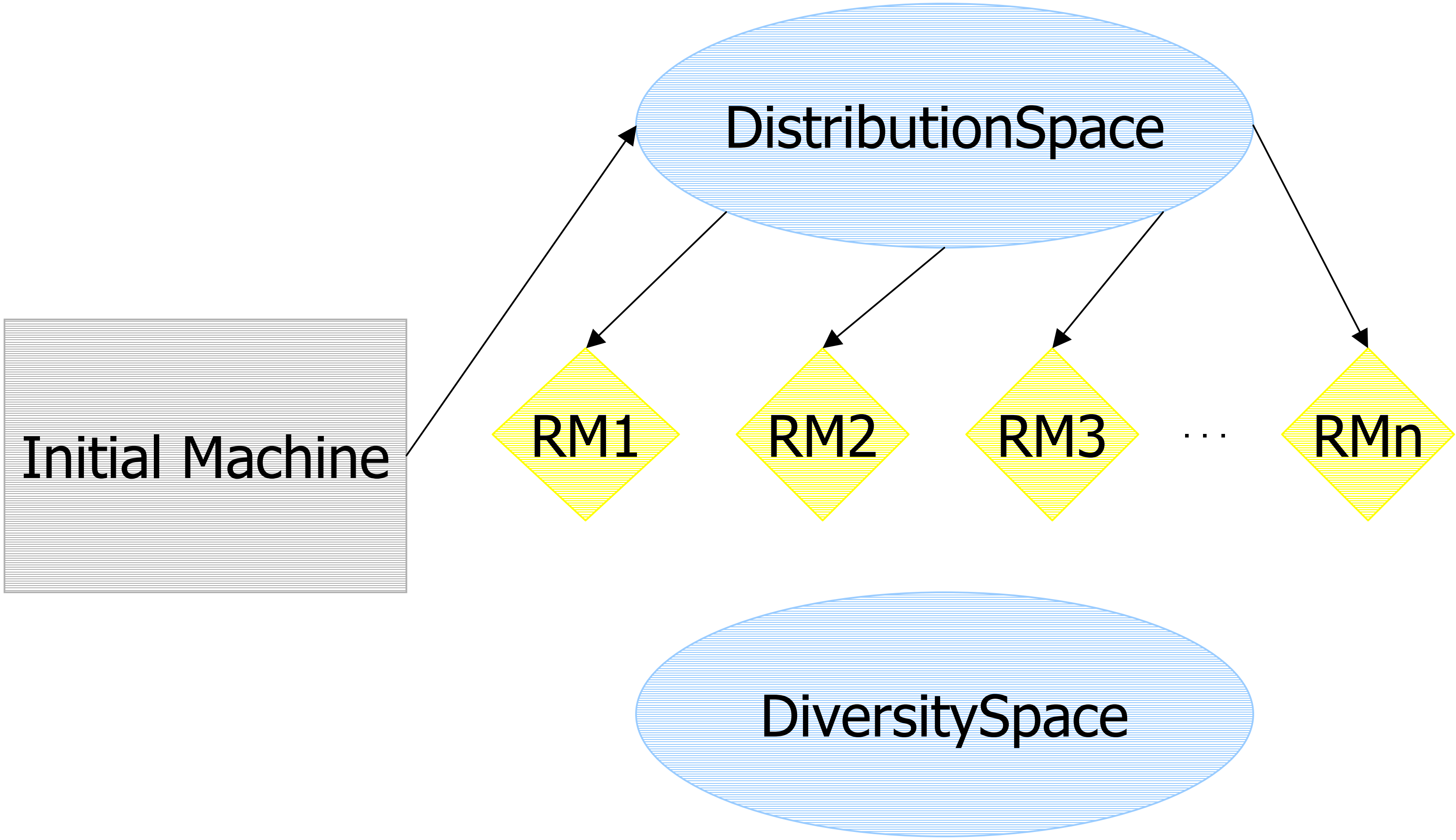


Allegheny College
Department of Computer Science

High Level Architecture: Entities in the “Simple” Model

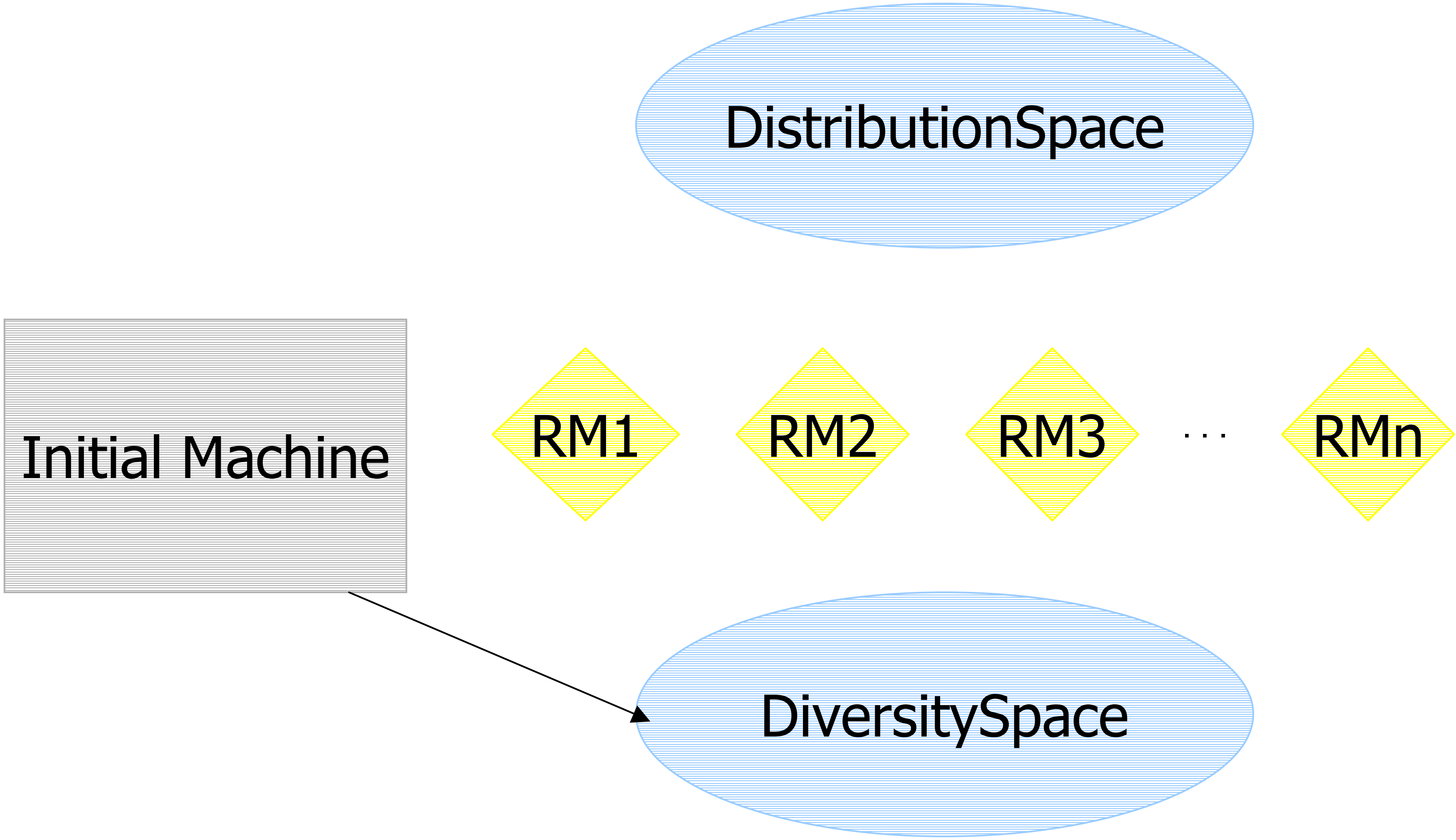


"Simple" Model: Distribution Phase



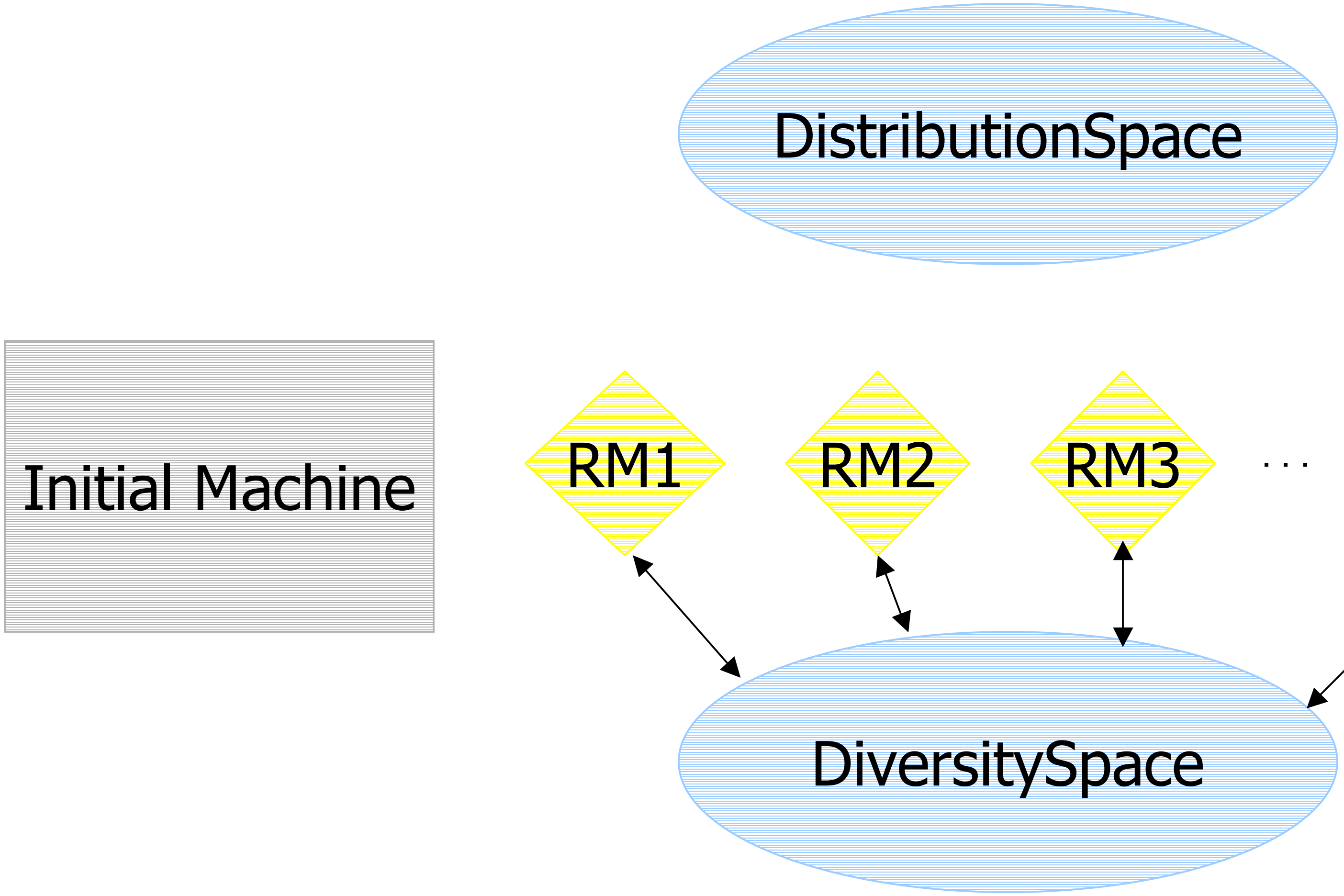
Allegheny College
Department of Computer Science

“Simple” Model: Pre-migration



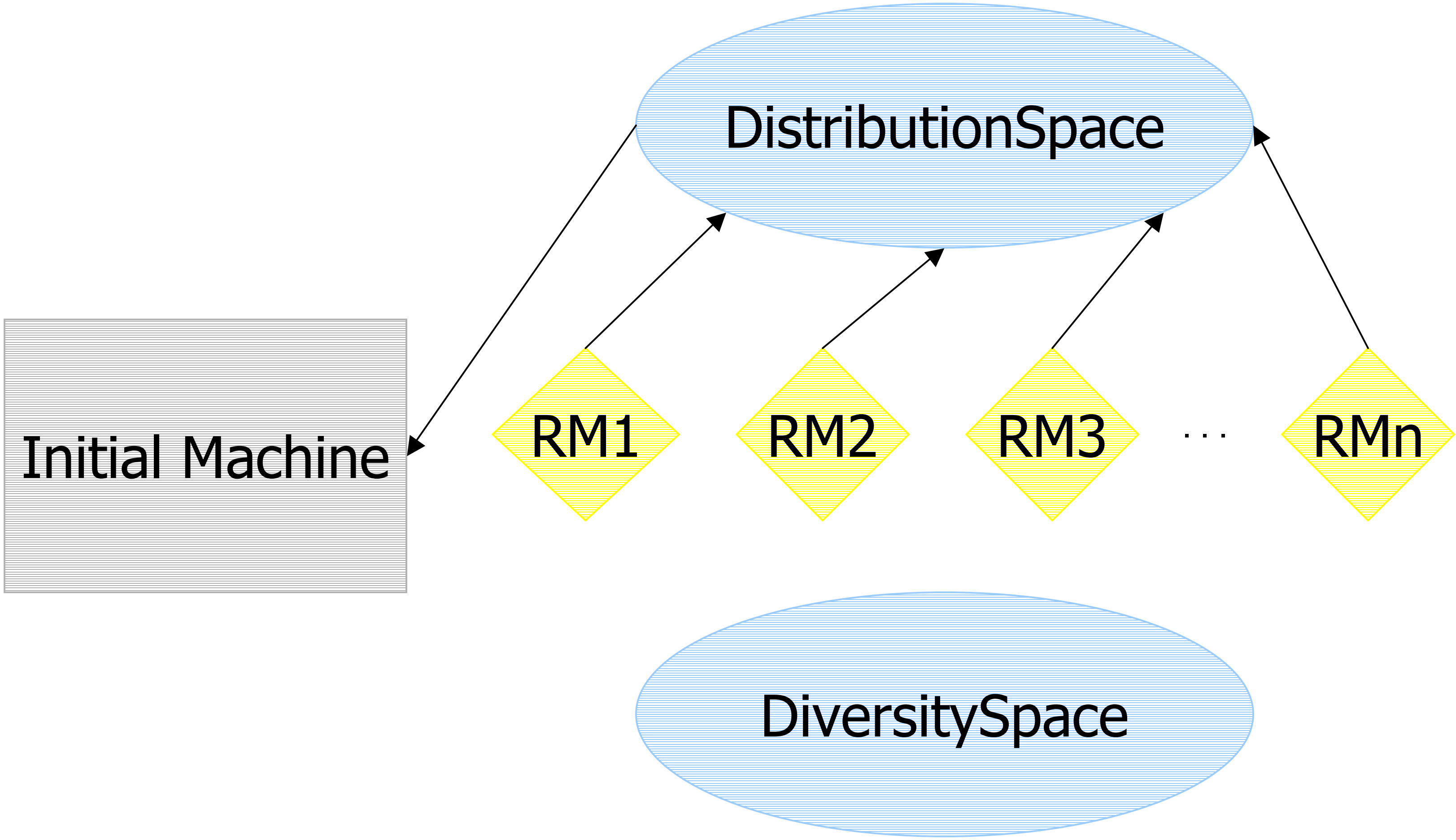
Department of Computer Science

"Simple" Model: Migration



Allegheny College
Department of Computer Science

"Simple" Model: Post-convergence

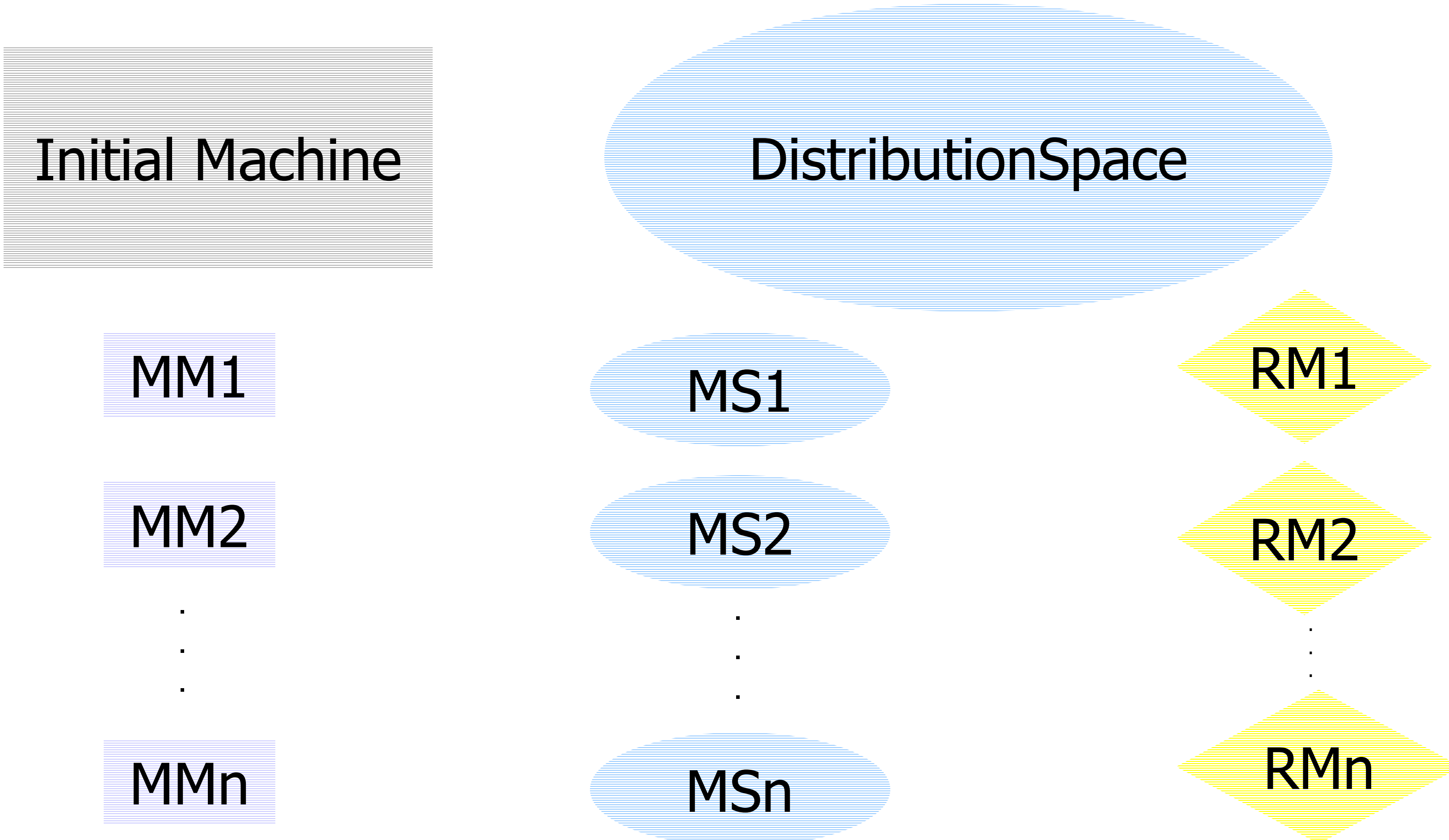


Simple Model Performance Bottleneck

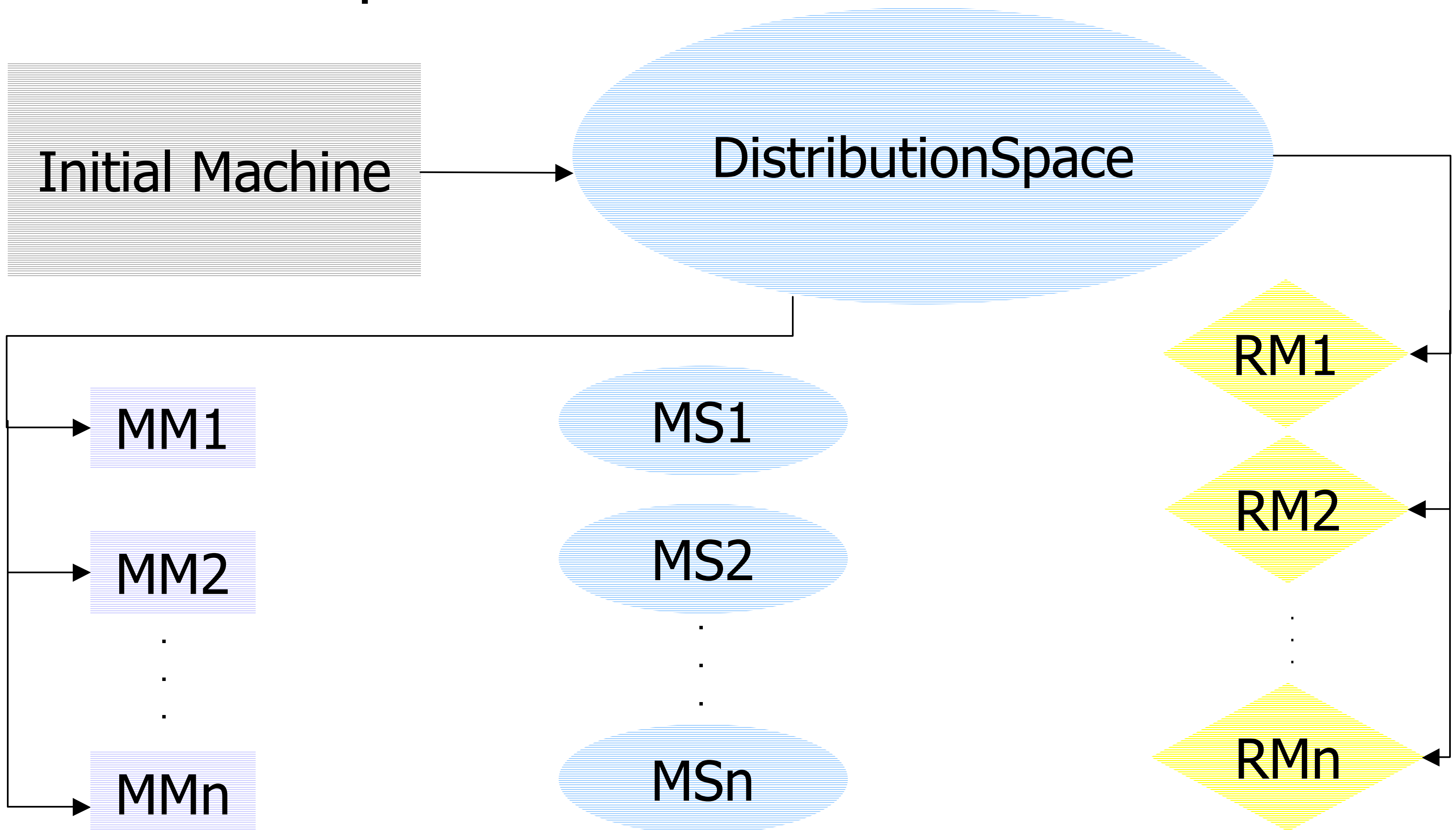
- No explicit synchronization between remote machines
- Potentially, each remote machine could migrate with JavaSpace at the same time!
- In some sense, this causes each worker to “wait in line” in order to perform migration!
- While each worker is waiting there is no computation!
- Designed “Complex” Distributed System Model (CDSM) in an attempt to reduce this bottleneck

Allegheny College
Department of Computer Science

High Level Architecture: Entities in the “Complex” Model

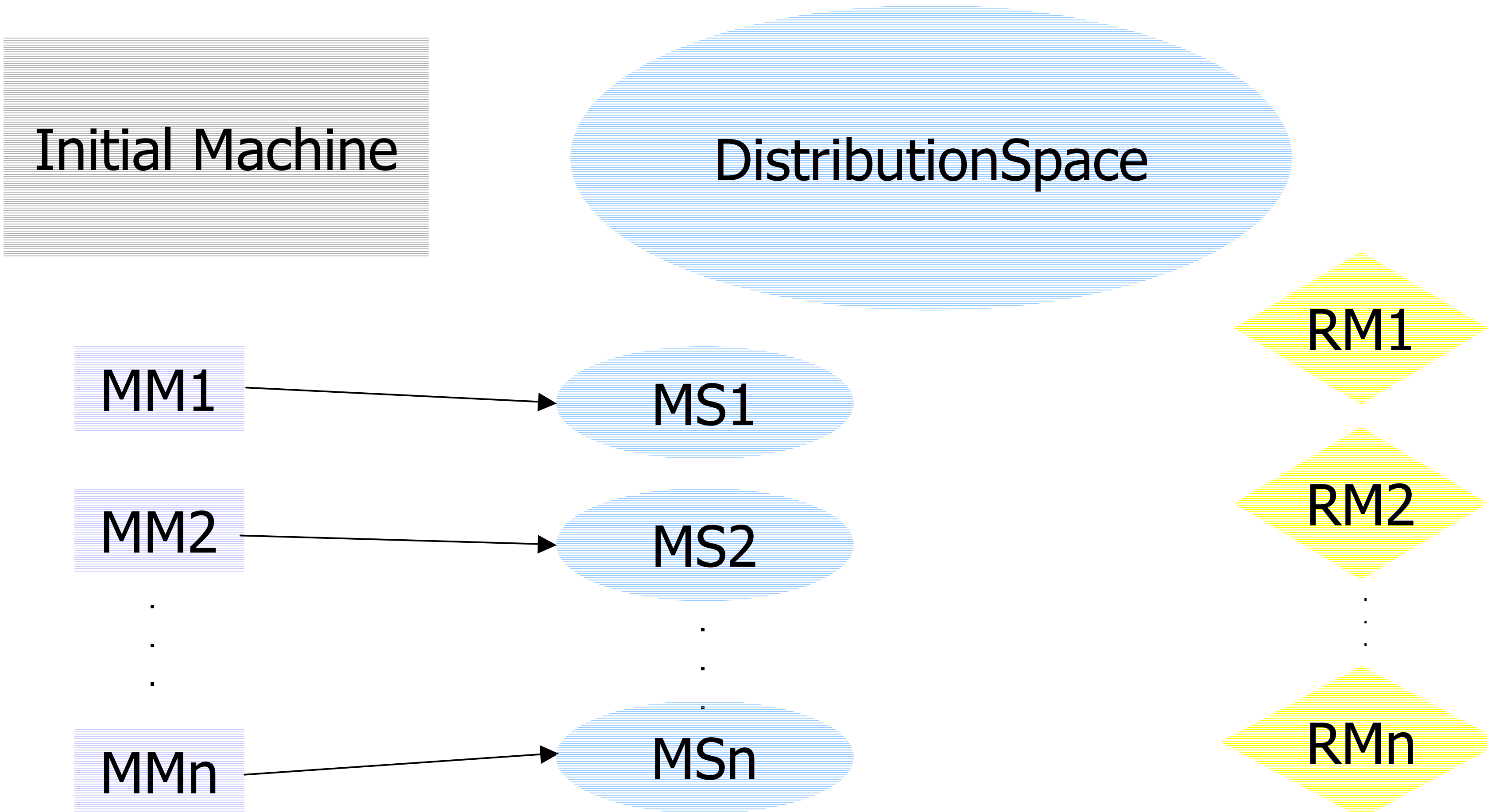


“Complex” Model: Distribution Phase

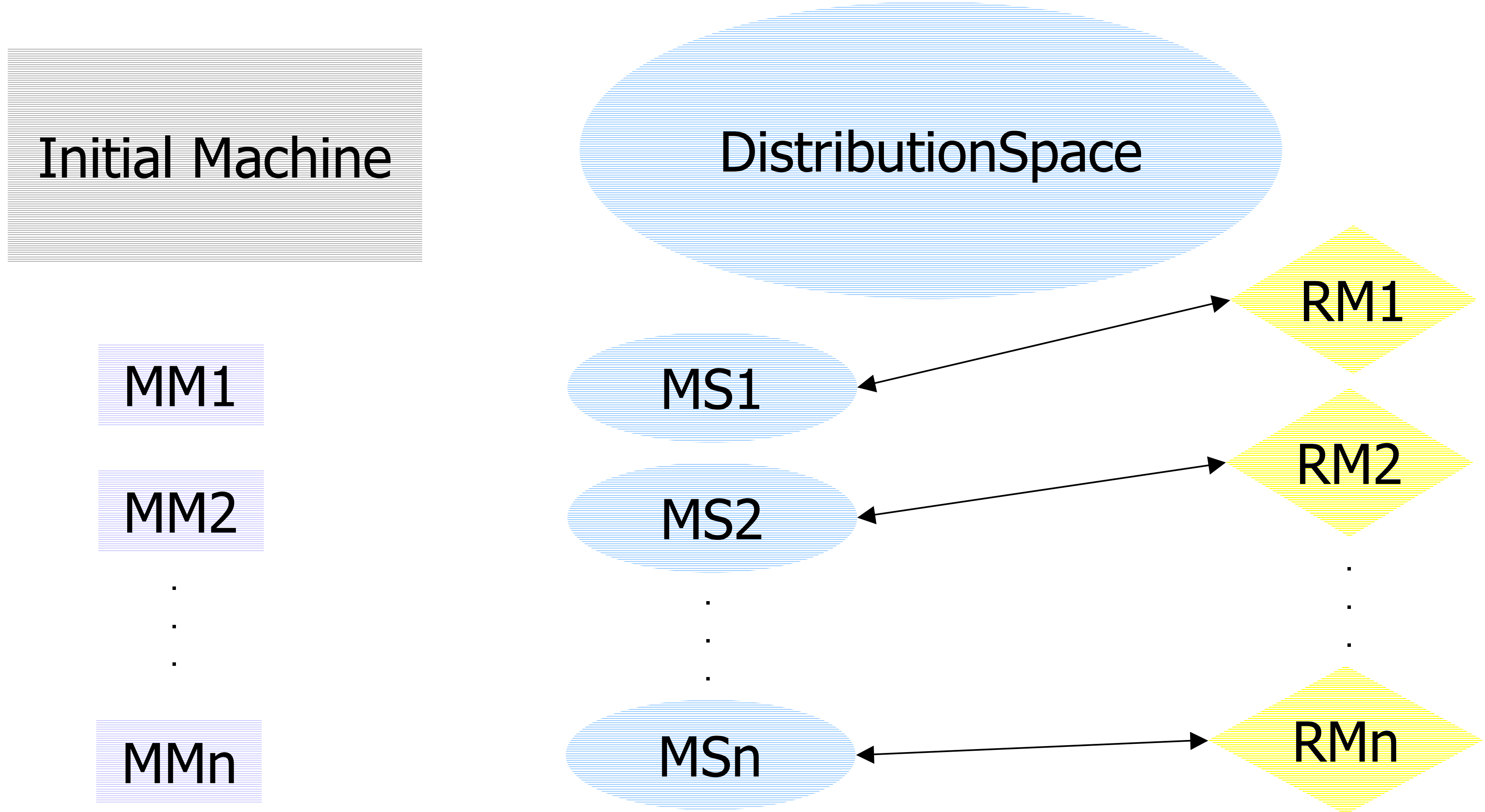


Allegheny College
Department of Computer Science

"Complex" Model: Pre-migration

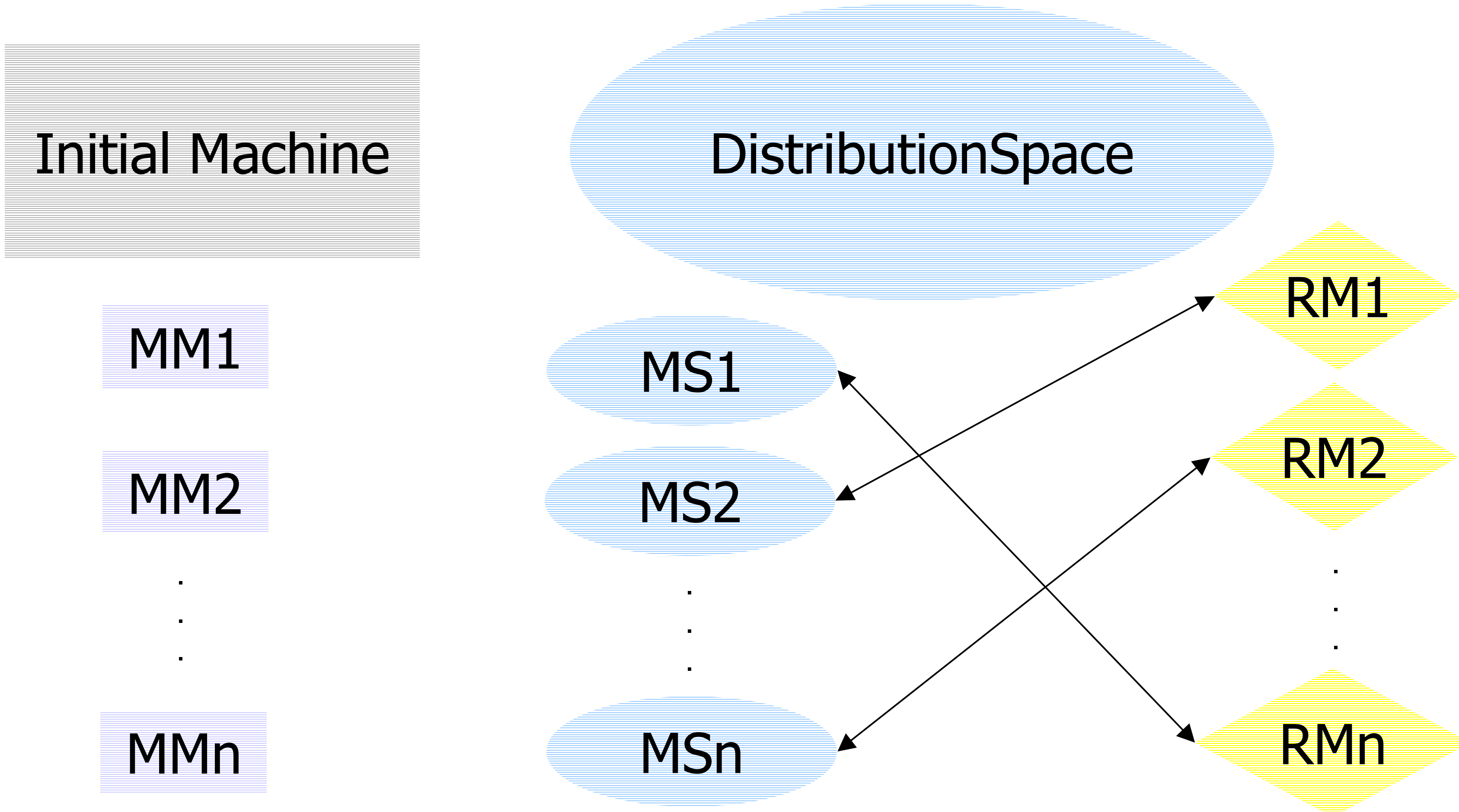


“Complex” Model: First Migration Phase

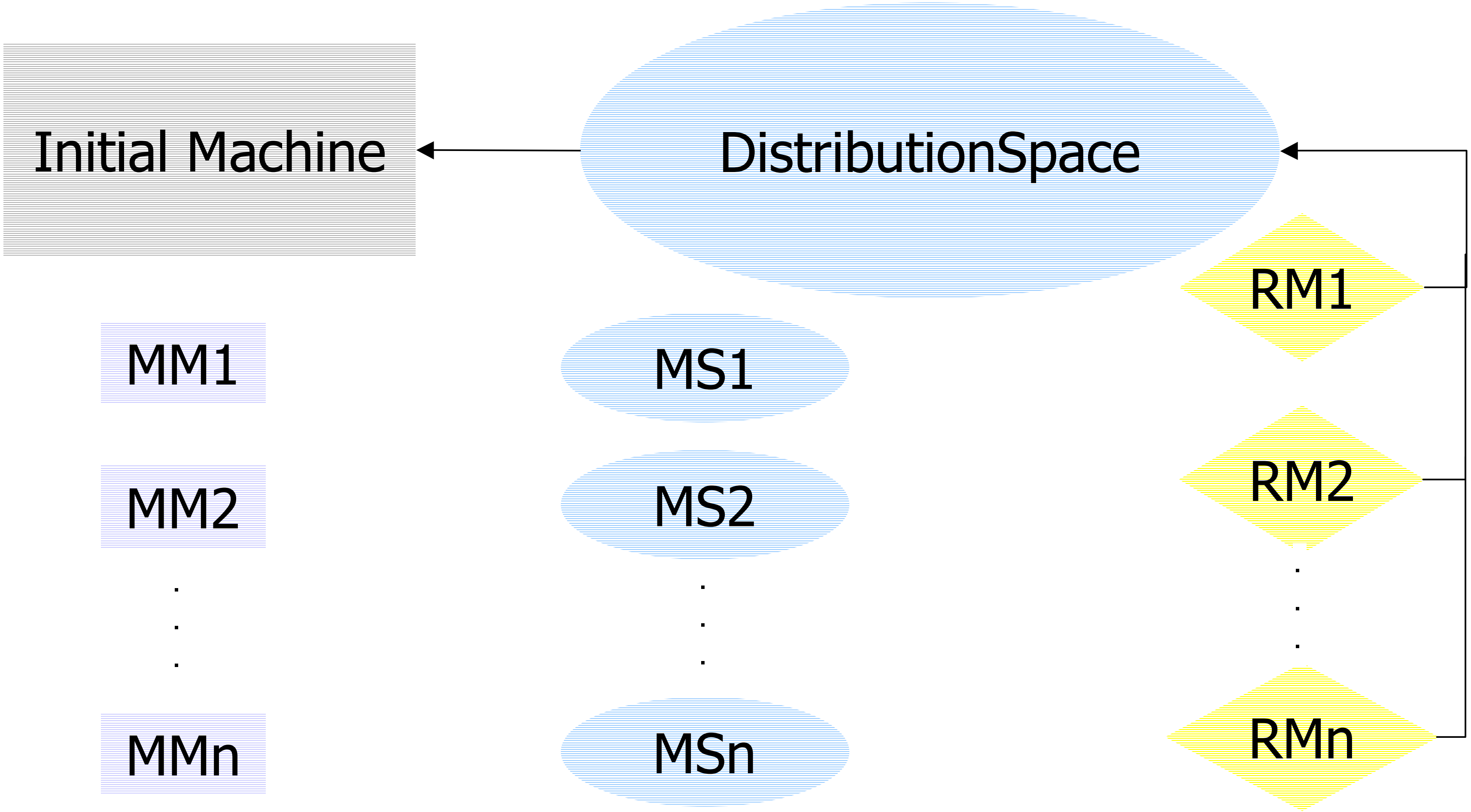


Allegheny College
Department of Computer Science

"Complex" Model: Subsequent Migration Phases



“Complex” Model: Post-convergence



"Complex" Model Observations

- Maintains the functionality of the "Simple" model
- Requires dedicated MigrationMachines and MigrationSpaces
- Explicit synchronization mechanism used so that chances of more than one remote machine migrating with the same JavaSpace at the same time is greatly reduced
- Multiple MigrationSpaces minimally reduce the overall diversity that any given remote machine has access to; however, this cost is small when compared to other gains!

Experimental Framework

- **Goal:** analyze the design and performance of the two models, and then compare the best version to sequential GA
- Selected open source GA written in Java that "solves" the Knapsack Problem
  - Knapsack problem is provably NP-complete
- **Knapsack Problem Statement:** Given a set of weights and knapsack capacity: find best combination of weights that fit inside the knapsack

Allegheny College
Department of Computer Science

Testbench Description

- 8 testsets of increasing levels of difficulty
- **Range of weight values:**
  0 – 5000
- **Number of weights**:
  500 – 1200
- **Number of machines**
  - SDSM: {2,4,6,8}
    - Requires RemoteMachines
  - CDSM: {2,4,6,8}
    - Requires RemoteMachines, MigrationMachines, MigrationSpaces

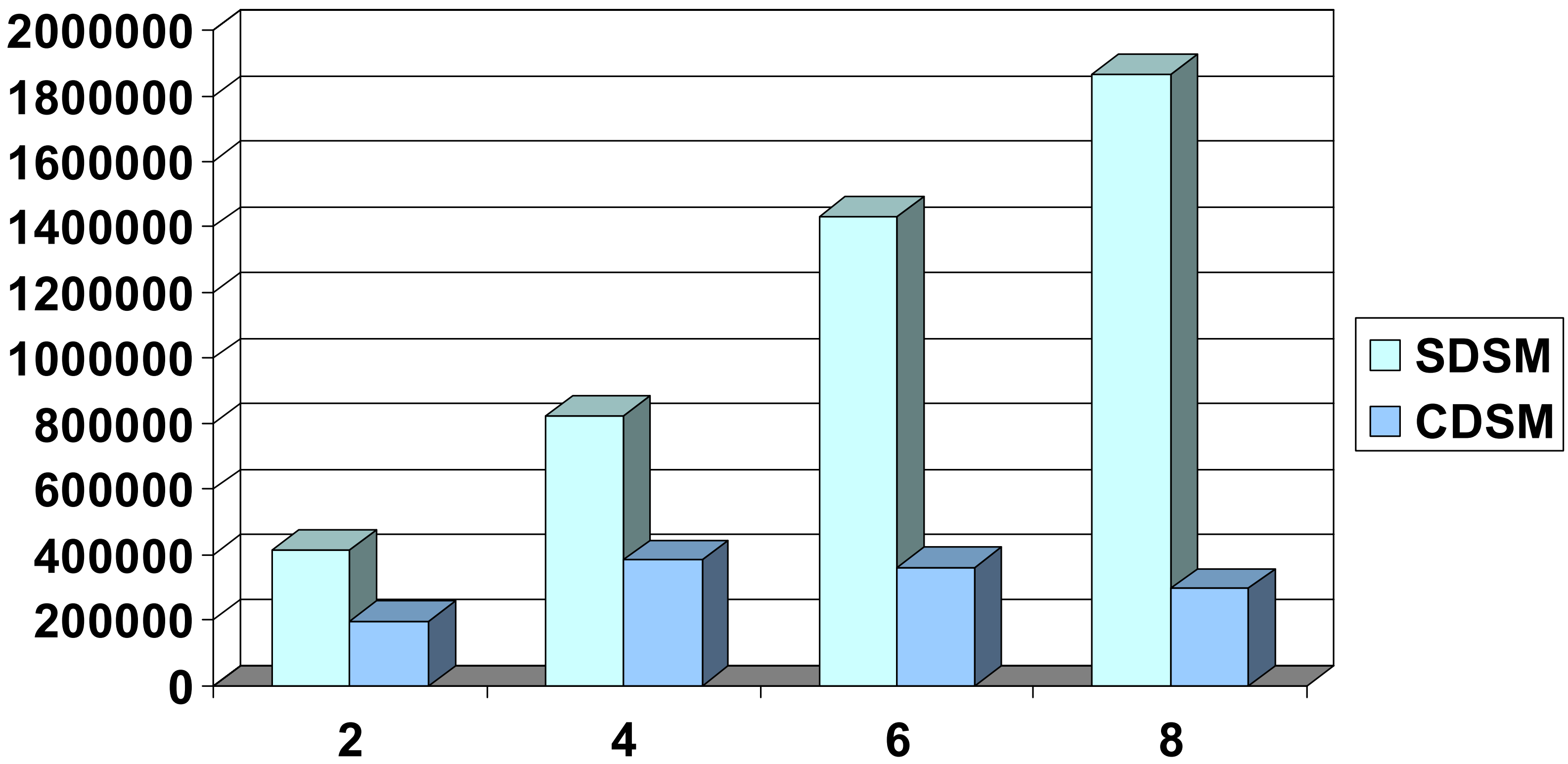
- **GA parameters:**
  - **Termination condition:** best solution remains constant after 75 generations
  - **Crossover**: at every generation
  - **Mutation:** at every generation
  - **Migration:** 30% of population every 30 generations, starting at generation 60

Measurements and General Observations

- **Execution time:** The CDSM reduces the execution time of the DGA when compared to the SDSM. Generally, overall execution time increases as we add machines to the CDSM.
- **Computation–to–Communication ratio:** CDSM increases this ratio when compared to the SDSM. The addition of machines to the CDSM reduces this ratio.
- **Diversity:** The potential for a higher quality solution increases as we move from the SGA to the CDSM and then as we add more machines to the CDSM.
- **Quality of Solution:** The QoS for the CDSM is always higher than the SGA. Generally, the QoS is higher in the CDSM as we add machines.
- **Generations–per–Second:** The CDSM can compute more Gen/Sec than the SDSM. Generally, adding more machines to the CDSM increases the Gen/Sec.

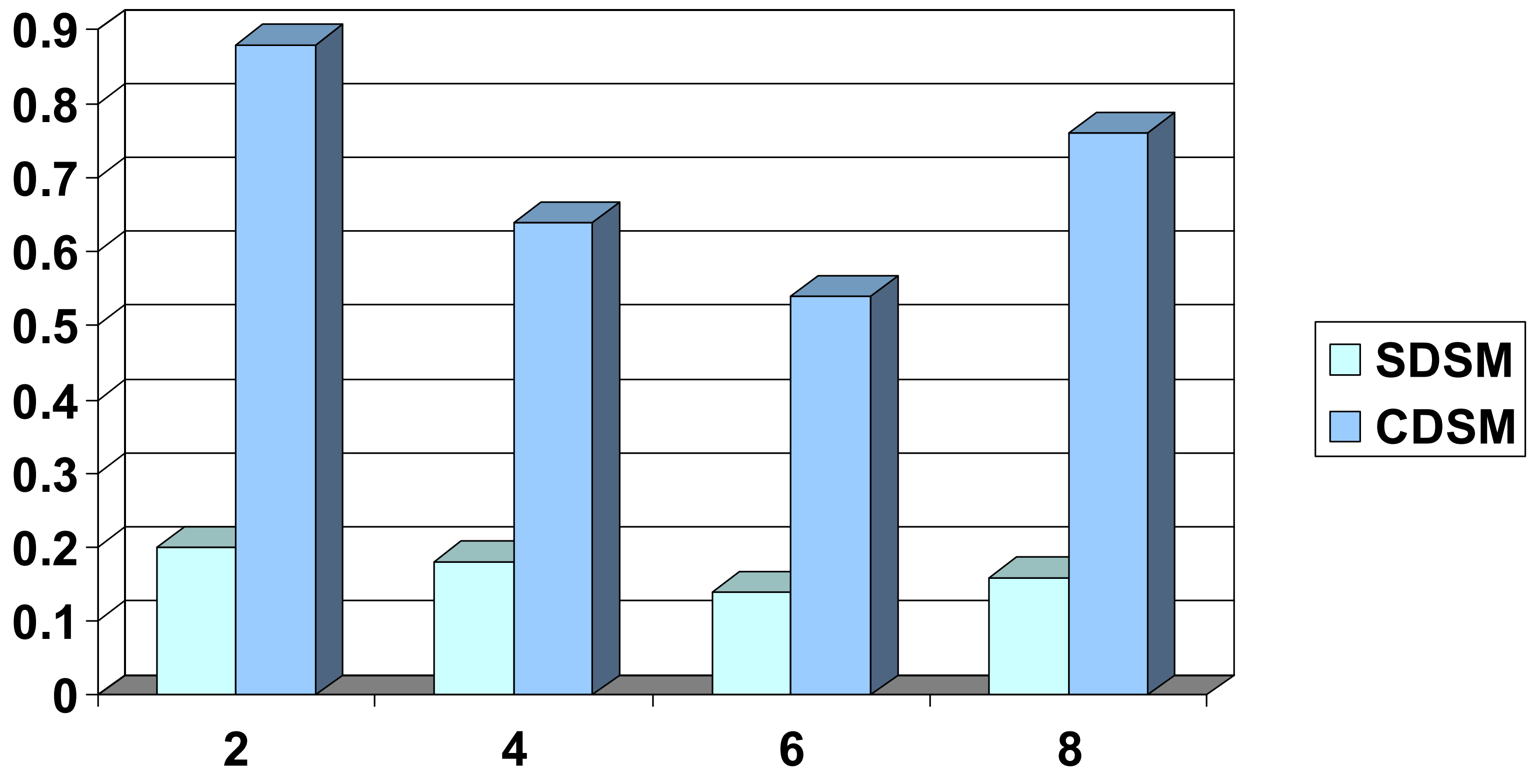
Allegheny College
Department of Computer Science

SDSM vs. CDSM: Execution time



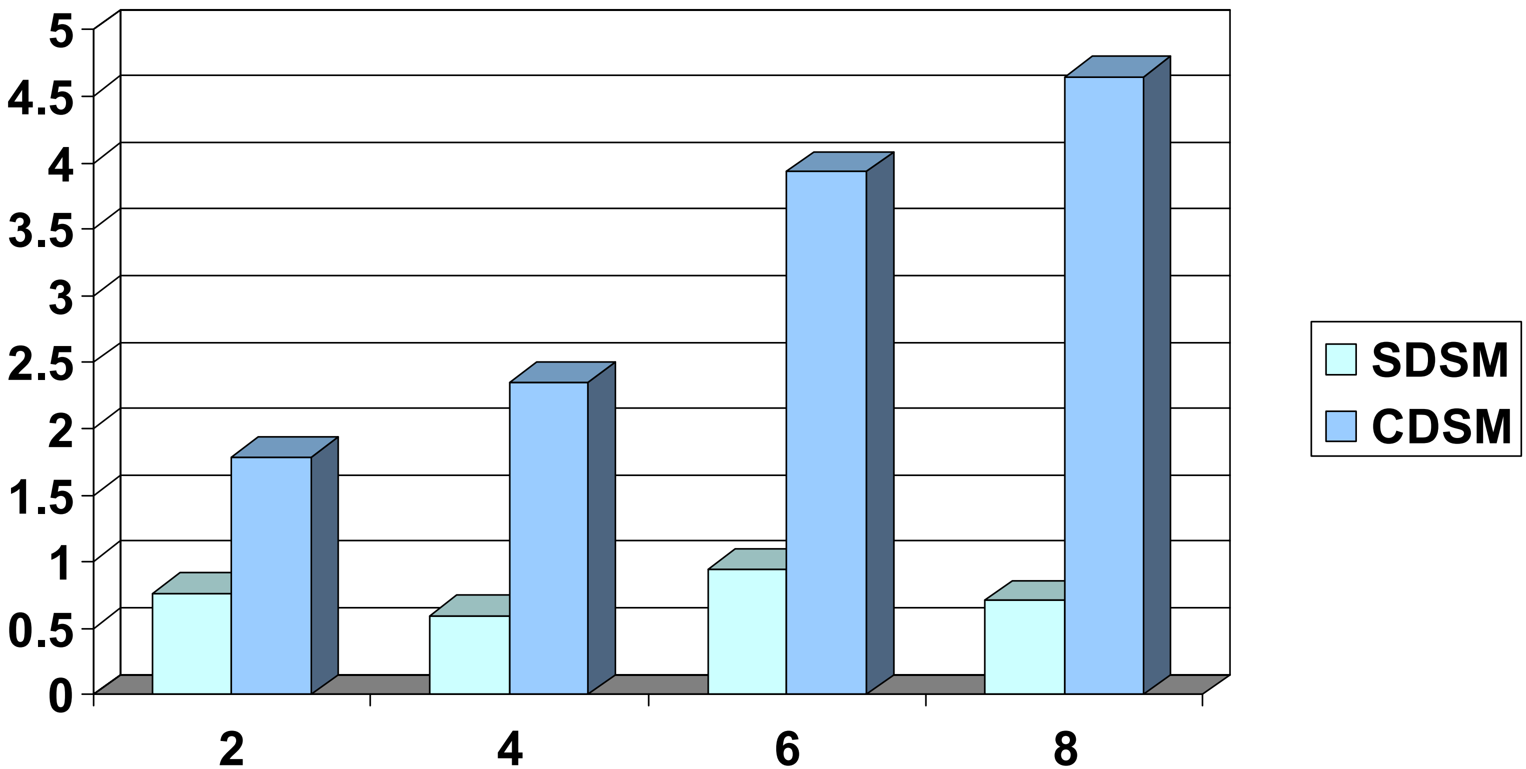
Allegheny College
Department of Computer Science

SDSM vs. CDSM: Computation-to-Communication Ratio



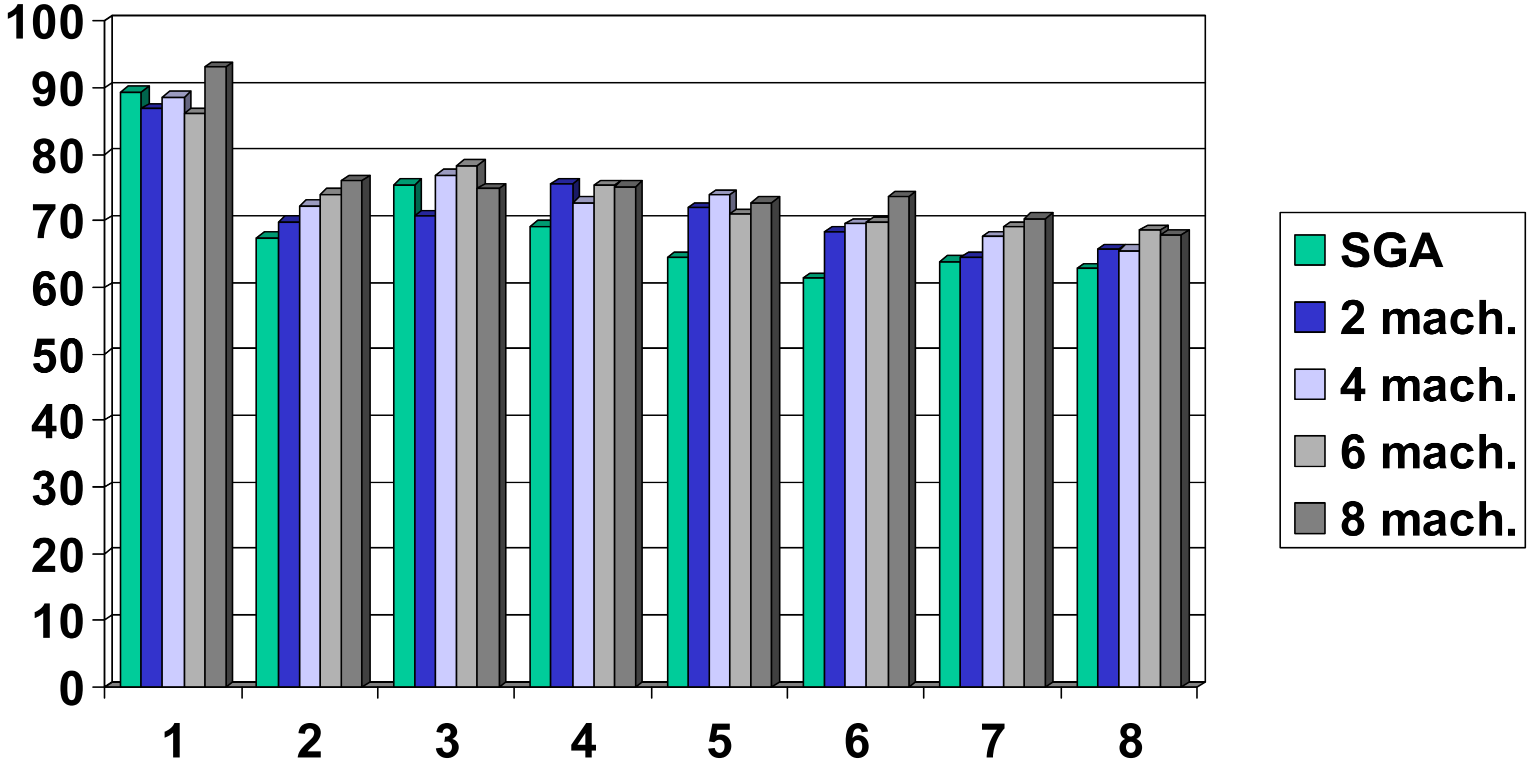
Allegheny College
Department of Computer Science

SDSM vs. CDSM: Generations/Second

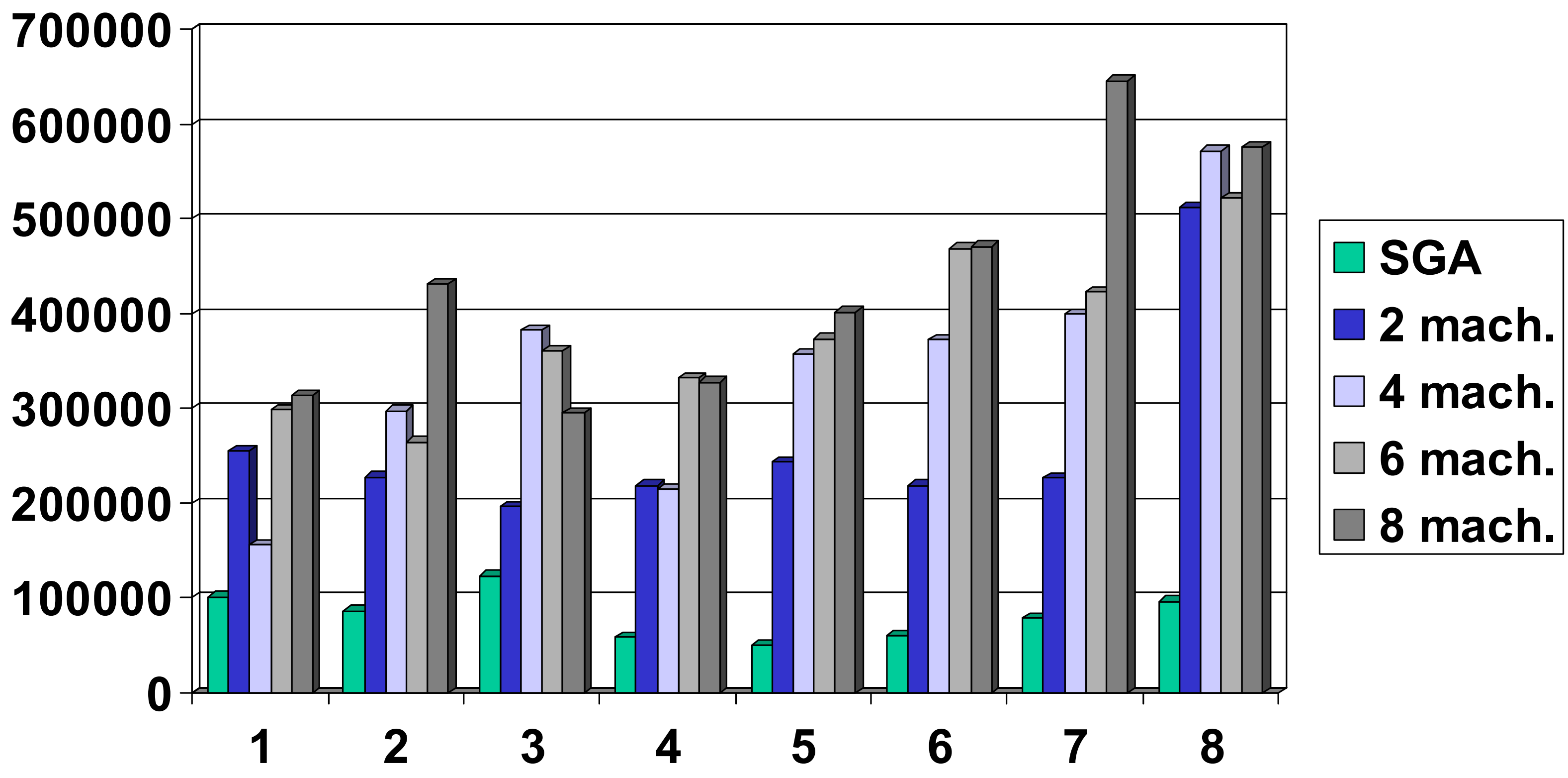


Department of Computer Science

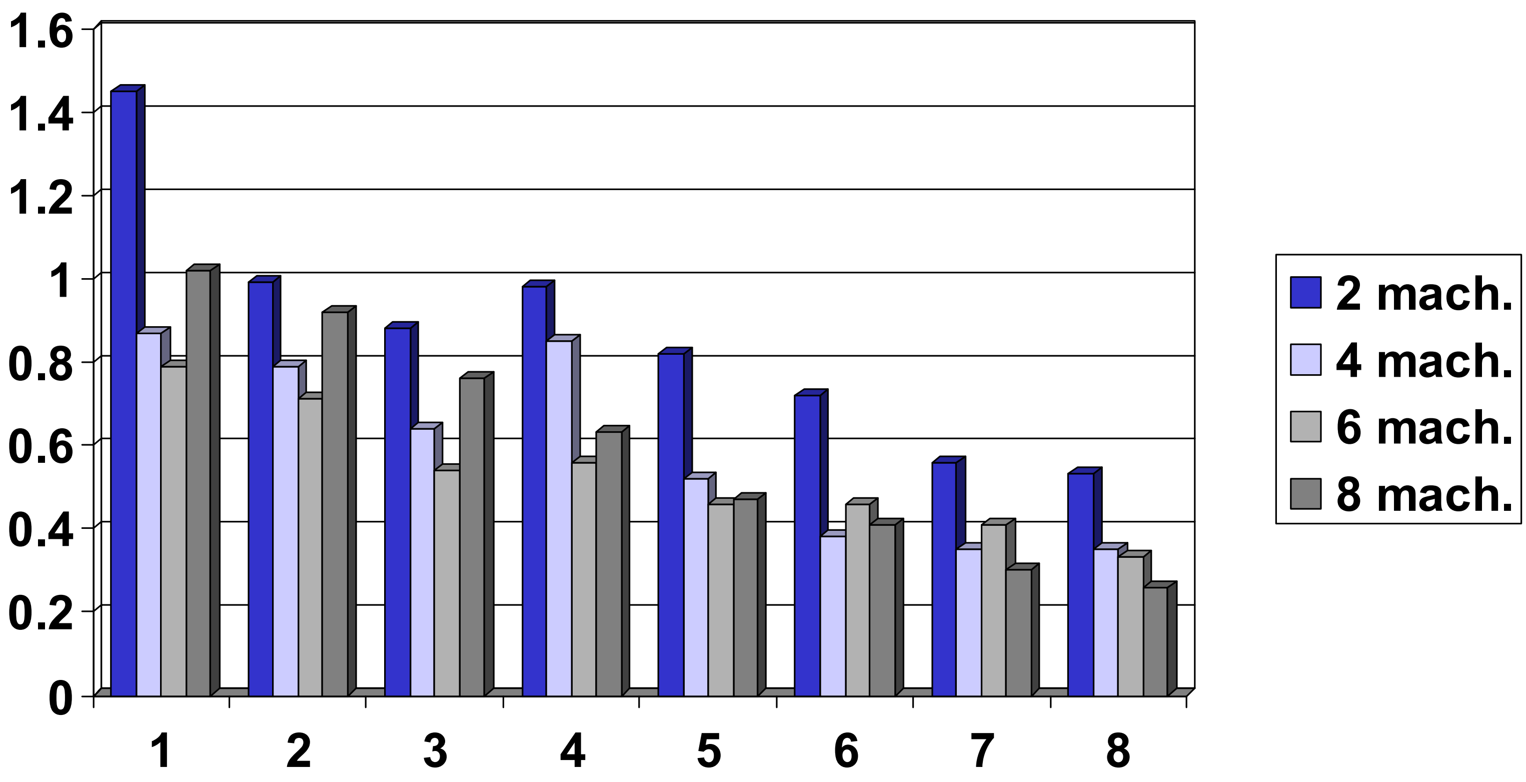
CDSM vs. SGA: Quality of Solution



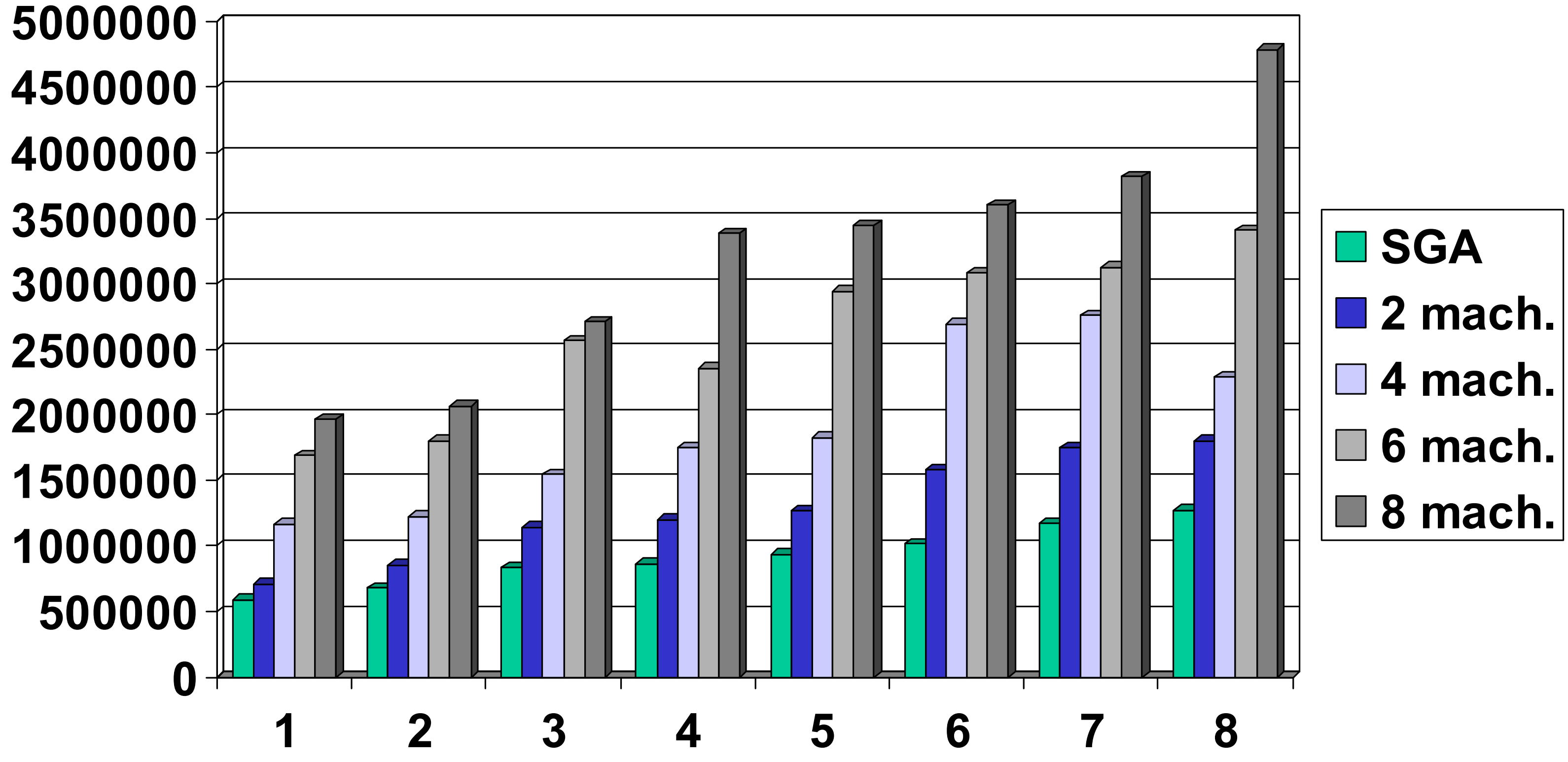
CDSM vs. SGA: Execution Time



CDSM vs. SGA: Computation-to-Communication



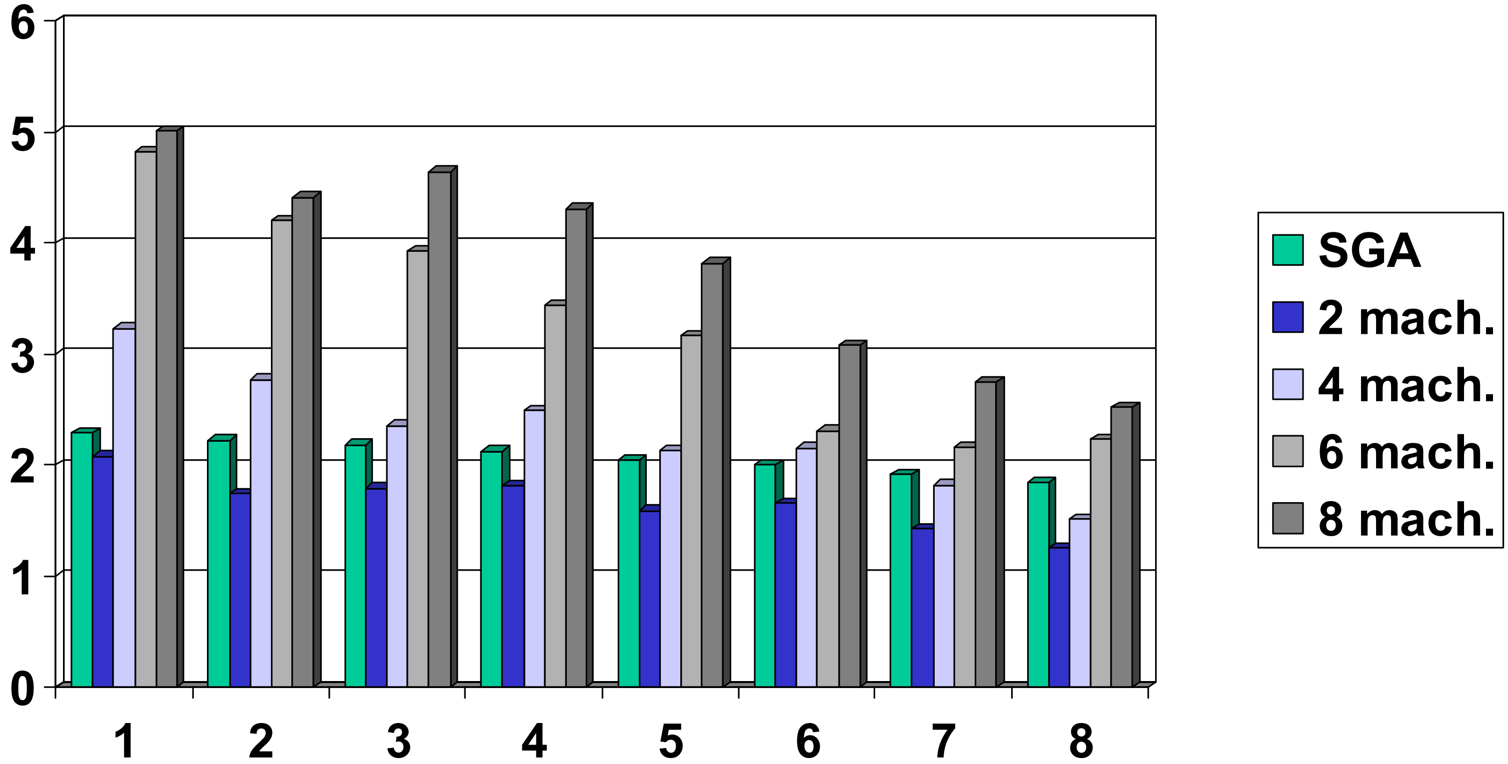
CDSM vs. SGA: Population Diversity



Allegheny College

Department of Computer Science

CDSM vs. SGA: Generations-per-Second



Allegheny College
Department of Computer Science

Future Possibilities: Distributed GA Framework

- Potential advantages of a DGA framework:
  - Could be integrated into existing Java GA frameworks
  - Java provides GA portability across operating systems
  - Jini and JavaSpaces offer openness, scalability, fault tolerance
  - GA developers could easily distribute their GA just to “see what happens”

- DGA framework would require an approach for automatically and transparently starting and terminating remote workers

- Various users should be able to donate their resources; our DGA can make use of “idle time” on various university machines

- Potentially, we could develop simple applet for visibility and learning

Allegheny College
Department of Computer Science

Concluding Remarks

- Investigated feasibility of using Jini and JavaSpaces to build a distributed genetic algorithm
- Proposed, implemented, and empirically evaluated a simple and a complex distributed system model (SDSM and CDSM)
- SDSM bottleneck was a serious concern that prompted the investigation of a new model that removed JavaSpaces interaction bottlenecks
- CDSM outperformed SGA in quality of solution, diversity, and generations per second
- SGA only outperformed CDSM in execution time (mostly due to early convergence)