EXAM TIMETABLE USING GA

Group 12 (11:20)

ABSTRACT

THIS REPORT INVESTIGATES THE APPLICATION OF GENETIC ALGORITHMS (GA) TO ADDRESS THE EXAM TIMETABLING PROBLEM, WHICH INVOLVES SCHEDULING EXAMINATIONS FOR STUDENTS IN A MANNER THAT MINIMIZES CONFLICTS, ENSURES RESOURCE EFFICIENCY, AND ADHERES TO CONSTRAINTS SUCH AS ROOM CAPACITY, EXAM DURATION, AND STUDENT COURSE OVERLAPS. THE OBJECTIVE IS TO DEVELOP AN ALGORITHM THAT GENERATES OPTIMAL TIMETABLES BY EVOLVING SOLUTIONS THROUGH GA PROCESSES. THE REPORT INCLUDES THE DESIGN, IMPLEMENTATION, AND RESULTS OF THE ALGORITHMS, ALONGSIDE A USER-FRIENDLY INTERFACE THAT VISUALIZES THE SCHEDULING PROCESS AND ALLOWS PARAMETER EXPERIMENTATION.

INTRODUCTION

PROBLEM STATEMENT

THE EXAM TIMETABLING PROBLEM (ETP) INVOLVES SCHEDULING EXAMS FOR MULTIPLE COURSES AND STUDENTS, ENSURING NO EXAM CONFLICTS FOR ANY STUDENT WHILE ADHERING TO ROOM CAPACITIES, EXAM DURATIONS, AND OTHER LOGISTICAL CONSTRAINTS. FINDING AN OPTIMAL SCHEDULE THAT MINIMIZES CONFLICTS AND RESOURCE OVERUSE, SUCH AS ROOM OVERBOOKING OR STUDENT OVERLOAD, IS A CHALLENGING TASK.

OBJECTIVE

THE GOAL OF THIS PROJECT IS TO IMPLEMENT A GENETIC ALGORITHM (GA) TO GENERATE VALID AND OPTIMIZED EXAM TIMETABLES, WHICH AVOID CONFLICTS AND EFFICIENTLY USE RESOURCES, WITH THE FLEXIBILITY TO EXPERIMENT WITH VARIOUS PARAMETERS AND ALGORITHMS.

DATASET INFO

DATASET DETAILS

NAME: UNIVERSITY EXAM SCHEDULING

LINK: HTTPS://WWW.KAGGLE.COM/DATASETS/SMREZWANULAZAD/EXAM-SCHEDULE

CONTAIN:
- CLASSROOMS.CSV
- COURSES.CSV
- INSTRUCTORS.CSV (NOT USED)
- SCHEDULE.CSV
- STUDENTS.CSV
- TIMESLOTS.CSV (WE GHANGE IN IT)

MORE DETAILS:

- 3000 STUDENTS
- 30 CLASSROOMS
- 22 COURSE
- 24 TIMESLOT

A DEFINE OF THE PROBLEM

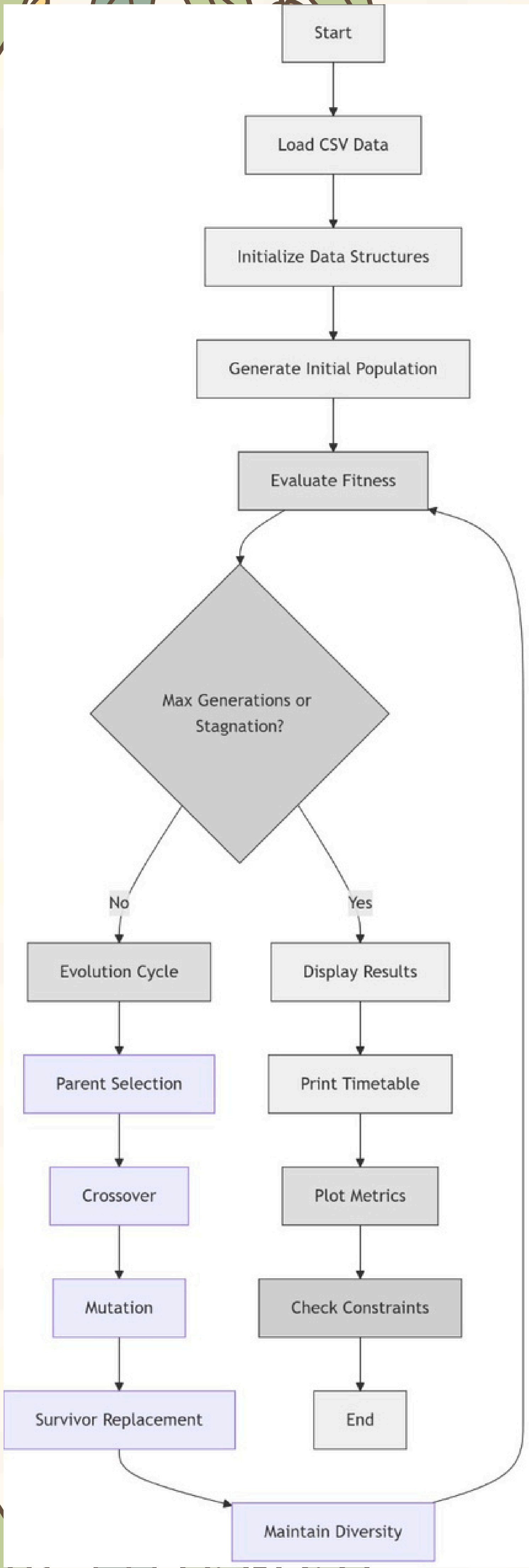
<u>PROBLEM FORMALIZATION</u>

PROBLEM TYPE: CONSTRAINED OPTIMIZATION PROBLEM

THE EXAM TIMETABLING PROBLEM (ETP) INVOLVES FINDING AN OPTIMAL SCHEDULE FOR A SET OF EXAMS WHILE SATISFYING MULTIPLE HARD AND SOFT CONSTRAINTS. THIS NATURALLY PLACES IT IN THE CATEGORY OF A CONSTRAINED OPTIMIZATION PROBLEM, WHERE:

- OBJECTIVE FUNCTION: WE AIM TO MINIMIZE THE TOTAL PENALTY ASSOCIATED WITH CONSTRAINT VIOLATIONS (E.G., STUDENT EXAM CLASHES, ROOM CAPACITY VIOLATIONS, TIGHTLY PACKED EXAMS).
- DECISION VARIABLES: ASSIGNMENTS OF EXAMS TO TIME SLOTS AND ROOMS.
- CONSTRAINTS:
  - HARD CONSTRAINTS (MUST BE SATISFIED):
    - STUDENT CONFLICTS: NO STUDENT CAN HAVE OVERLAPPING EXAMS.
    - ROOM CAPACITIES: ROOMS MUST ACCOMMODATE ALL STUDENTS TAKING AN EXAM.
    - TIME SLOT CONSTRAINTS: NO TWO EXAMS FOR THE SAME STUDENT CAN SHARE A TIME SLOT.
    - ROOM AVAILABILITY: A ROOM CAN HOST ONLY ONE EXAM AT A TIME.
  - SOFT CONSTRAINTS (PREFERRED BUT NOT MANDATORY):
    - SPACING BETWEEN EXAMS: PREFER GAPS BETWEEN EXAMS FOR STUDENT REST.
    - AVOID HARD SUBJECT COMBINATIONS: SPACE OUT DIFFICULT SUBJECTS TO REDUCE FATIGUE.
    - EXAM DISTRIBUTION ACROSS DAYS: SPREAD EXAMS OVER MULTIPLE DAYS TO LOWER STRESS.
    - STUDENT REST PERIODS: ALLOW REST DAYS BETWEEN TOUGH EXAMS.

FLOW CHART


Start
Load CSV Data
Initialize Data Structures
Generate Initial Population
Evaluate Fitness
Max Generations or Stagnation?
No
Yes
Evolution Cycle
Parent Selection
Crossover
Mutation
Survivor Replacement
Maintain Diversity
Display Results
Print Timetable
Plot Metrics
Check Constraints
End

B.CONSTRAINT HANDLING

CONSTRAINT HANDLING TYPE: PENALTY FUNCTION , REPAIR FUNCTION

1. PENALTY FUNCTIONS (MAIN TECHNIQUE)
WE APPLY PENALTY FUNCTIONS TO INTEGRATE BOTH HARD AND SOFT CONSTRAINTS DIRECTLY INTO THE FITNESS FUNCTION. THIS TRANSFORMS CONSTRAINT VIOLATIONS INTO NUMERICAL PENALTIES THAT NEGATIVELY IMPACT SOLUTION QUALITY.

WHY PENALTY FUNCTIONS?

- ALLOWS EXPLORATION OF BOTH FEASIBLE AND INFEASIBLE SOLUTIONS.
- PENALIZES VIOLATIONS PROPORTIONALLY, ENSURING WORSE VIOLATIONS LEAD TO GREATER PENALTIES.
- GUIDES THE SEARCH TOWARD MORE FEASIBLE SOLUTIONS WHILE STILL ALLOWING DIVERSITY.
- SOFT CONSTRAINTS (LIKE BALANCED STUDENT LOAD OR ROOM UTILIZATION) ARE INCORPORATED WITHOUT STRICTLY ENFORCING THEM.

2. REPAIR FUNCTIONS (SUPPORTIVE TECHNIQUE)
IN ADDITION TO PENALTIES, WE APPLY REPAIR FUNCTIONS TO CORRECT SPECIFIC TYPES OF CONSTRAINT VIOLATIONS IMMEDIATELY AFTER SOLUTION GENERATION (E.G., AFTER CROSSOVER OR MUTATION).

WHY REPAIR FUNCTIONS?

- FIX HARD CONSTRAINT VIOLATIONS DIRECTLY.
- IMPROVE FEASIBILITY OF OFFSPRING BEFORE EVALUATION.
- REDUCE THE BURDEN ON THE FITNESS FUNCTION BY PRE-CORRECTING CRITICAL ISSUES.

C. COEVOLUTIONARY APPROACH

IF WE DID IT
COEVOLUTIONARY APPROACH TYPE: COOPERATIVE

THIS SECTION IS OPTIONAL, AND WE DID NOT IMPLEMENT A COEVOLUTIONARY APPROACH FOR OUR EXAM TIMETABLING OPTIMIZATION PROJECT.

REASONING

- PROBLEM DECOMPOSITION NOT NEEDED: THE PROBLEM DID NOT NATURALLY DECOMPOSE INTO SUBCOMPONENTS THAT REQUIRE SEPARATE POPULATIONS (E.G., COEVOLVING STUDENTS VS. ROOMS).
- COMPLEXITY AVOIDANCE: COEVOLUTION ADDS COMPLEXITY IN TERMS OF FITNESS SHARING, INTERACTION EVALUATION, AND SYNCHRONIZATION BETWEEN POPULATIONS.

D.E.F. COMPONENTS

1. REPRESENTATION (DEFINITION OF INDIVIDUALS)

WE USED ONE TYPE OF REPRESENTATION:

- STRUCTURED REPRESENTATION: A DICTIONARY MAPPING EACH COURSE TO A TUPLE OF (TIMESLOT, LIST OF ROOM ASSIGNMENTS) TO ALLOW EXPLICIT TRACKING OF ROOM ALLOCATIONS AND STUDENT DISTRIBUTION.

2. INITIALIZATION

WE EMPLOYED THREE INITIALIZATION APPROACHES:

- RANDOM INITIALIZATION: EXAMS ARE RANDOMLY ASSIGNED TO TIMESLOTS AND ROOMS, ENSURING A DIVERSE STARTING POPULATION.
- HEURISTIC INITIALIZATION: EXAMS WITH THE HIGHEST STUDENT CONFLICT (LARGEST DEGREE IN A CONFLICT GRAPH) ARE SCHEDULED FIRST IN THE MOST APPROPRIATE SLOTS, REDUCING EARLY CLASHES.
- SIZE-BASED APPROACH: SCHEDULES EXAMS WITH THE LARGEST ENROLLMENT FIRST, PLACING THEM IN THE MOST SUITABLE (E.G., HIGHEST-CAPACITY) ROOMS TO REDUCE FRAGMENTATION AND CONFLICTS.

3. EVALUATION FUNCTION (FITNESS FUNCTION)

WE USED A HYBRID PENALTY-BASED FITNESS FUNCTION, DEFINED IN HYBRID_FITNESS(). IT ASSIGNS PENALTIES FOR:

- HARD CONSTRAINTS (E.G., STUDENT CLASHES, ROOM OVERCAPACITY, MISSING EXAMS).
- SOFT CONSTRAINTS (E.G., TIGHT EXAM SPACING FOR STUDENTS, ROOM UNDERUTILIZATION, CLUSTERING OF DIFFICULT SUBJECTS).

THE TOTAL PENALTY IS MINIMIZED. A LOWER SCORE MEANS A BETTER TIMETABLE.

4. PARENT SELECTION MECHANISM

WE IMPLEMENTED THREE SELECTION STRATEGIES:

- TOURNAMENT SELECTION: RANDOMLY SELECTS A GROUP OF INDIVIDUALS AND PICKS THE BEST ONE BASED ON FITNESS.
- ROULETTE WHEEL SELECTION: PROBABILISTIC SELECTION BASED ON FITNESS-PROPORTIONAL PROBABILITIES. FITTER INDIVIDUALS HAVE A HIGHER CHANCE OF BEING SELECTED.
- EXPONENTIAL RANK: RANKS INDIVIDUALS BY FITNESS AND ASSIGNS EXPONENTIALLY WEIGHTED PROBABILITIES, FAVORING HIGHER-RANKED SOLUTIONS MORE AGGRESSIVELY THAN LINEAR RANKING.

D.E.F.COMPONENTS

5. VARIATION OPERATORS

CROSSOVER (RECOMBINATION)

THREE TYPES OF RECOMBINATION OPERATORS WERE IMPLEMENTED:

- UNIFORM CROSSOVER: EACH GENE (EXAM ASSIGNMENT) IS INDEPENDENTLY SWAPPED BETWEEN PARENTS WITH A FIXED PROBABILITY.
- SINGLE-POINT CROSSOVER: A SINGLE CUT POINT IS CHOSEN, AND ALL GENES BEYOND IT ARE SWAPPED BETWEEN PARENTS.
- TWO-POINT CROSSOVER: TWO CROSSOVER POINTS ARE SELECTED AND A SEGMENT OF GENES BETWEEN PARENTS IS EXCHANGED.

MUTATION

WE APPLIED MULTIPLE SPECIALIZED MUTATION OPERATORS:

- TIMESLOT MUTATION: RANDOMLY REASSIGNS AN EXAM TO A DIFFERENT TIMESLOT.
- ROOM ASSIGNMENT MUTATION: ALTERS THE ROOM(S) ASSIGNED TO AN EXAM.
- DAY CHANGE MUTATION: SHIFTS THE EXAM TO A DIFFERENT DAY.
- SPLIT ROOMS MUTATION: DISTRIBUTES STUDENTS ACROSS MULTIPLE ROOMS DIFFERENTLY TO IMPROVE ROOM USAGE.

6. SURVIVOR SELECTION MECHANISM (REPLACEMENT STRATEGY)

MULTIPLE SURVIVOR STRATEGIES WERE EXPLORED:

- STEADY-STATE REPLACEMENT: ONLY A FEW OFFSPRING REPLACE THE WORST INDIVIDUALS IN THE POPULATION.
- ELITISM: A FIXED NUMBER OF TOP INDIVIDUALS ARE ALWAYS PRESERVED FOR THE NEXT GENERATION.
- GENERATIONAL REPLACEMENT: THE ENTIRE POPULATION IS REPLACED EACH GENERATION BY THE NEW OFFSPRING.

7. TERMINATION CONDITIONS

WE USED A STAGNATION-BASED TERMINATION STRATEGY:

- IF NO IMPROVEMENT IS OBSERVED IN THE BEST FITNESS FOR SELF.MAX_STAGNATION CONSECUTIVE GENERATIONS, THE ALGORITHM HALTS.

THIS AVOIDS UNNECESSARY COMPUTATION WHEN THE SEARCH HAS CONVERGED.

G.CONTROL/TUNE THE PARAMETERS

IN OUR GENETIC ALGORITHM-BASED EXAM TIMETABLING SYSTEM, WE EMPLOYED ADAPTIVE PARAMETER CONTROL TO DYNAMICALLY ADJUST ALGORITHM PARAMETERS DURING EXECUTION. THIS APPROACH HELPS MAINTAIN A BALANCE BETWEEN EXPLORATION (DIVERSITY) AND EXPLOITATION (REFINEMENT), IMPROVING CONVERGENCE TO HIGH-QUALITY SOLUTIONS.

PARAMETER TUNING

PARAMETER TUNING REFERS TO SELECTING THE BEST FIXED VALUES FOR PARAMETERS (E.G., MUTATION RATE = 0.1, CROSSOVER RATE = 0.8) BEFORE RUNNING THE ALGORITHM. IT USUALLY INVOLVES MANUAL EXPERIMENTATION OR META-OPTIMIZATION METHODS.

PARAMETER CONTROL

PARAMETER CONTROL REFERS TO TECHNIQUES THAT CHANGE ALGORITHM PARAMETERS (LIKE MUTATION RATE, CROSSOVER RATE, ETC.) DURING THE RUN OF THE ALGORITHM RATHER THAN KEEPING THEM FIXED. THIS MAKES THE ALGORITHM MORE FLEXIBLE AND RESPONSIVE TO CURRENT SEARCH CONDITIONS.

OUR APPROACH: ADAPTIVE PARAMETER CONTROL

WE USED AN ADAPTIVE CONTROL MECHANISM WHERE THE MUTATION AND CROSSOVER RATES ARE ADJUSTED BASED ON THE SUCCESS RATE OF OFFSPRING IN IMPROVING THE POPULATION. THIS IS DONE AS FOLLOWS:

- SUCCESS-BASED ADJUSTMENT:
  - IF A NEW GENERATION YIELDS BETTER OFFSPRING (LOWER PENALTY), THE CURRENT MUTATION/CROSSOVER RATE IS SLIGHTLY INCREASED TO CONTINUE SUCCESSFUL EXPLORATION.
  - IF NO IMPROVEMENT OCCURS OVER SUCCESSIVE GENERATIONS, RATES ARE REDUCED OR SHIFTED TO EXPLORE OTHER REGIONS.

BENEFITS OF ADAPTIVE CONTROL

- AUTOMATICALLY BALANCES EXPLORATION VS. EXPLOITATION.
- REDUCES THE NEW FOR EXTENSIVE MANUAL TUNING.

H.DIVERSITY PRESERVATION

MAINTAINING DIVERSITY IN THE POPULATION IS ESSENTIAL IN EVOLUTIONARY ALGORITHMS TO AVOID PREMATURE CONVERGENCE, WHERE THE POPULATION GETS STUCK IN A SUBOPTIMAL SOLUTION. TO ENSURE DIVERSITY AND IMPROVE EXPLORATION, WE IMPLEMENTED THE FOLLOWING TWO STRATEGIES:

FITNESS SHARING

IT REDUCES THE FITNESS OF SIMILAR INDIVIDUALS TO PROMOTE DIVERSITY. IF MANY INDIVIDUALS OCCUPY THE SAME REGION IN THE SOLUTION SPACE, THEIR SHARED FITNESS IS DECREASED, MAKING OTHER, MORE DIVERSE INDIVIDUALS MORE LIKELY TO BE SELECTED.

- FOR EACH INDIVIDUAL, WE COMPUTE ITS SIMILARITY (E.G., HOW SIMILAR THEIR TIMETABLES ARE) WITH ALL OTHERS.

CROWDING

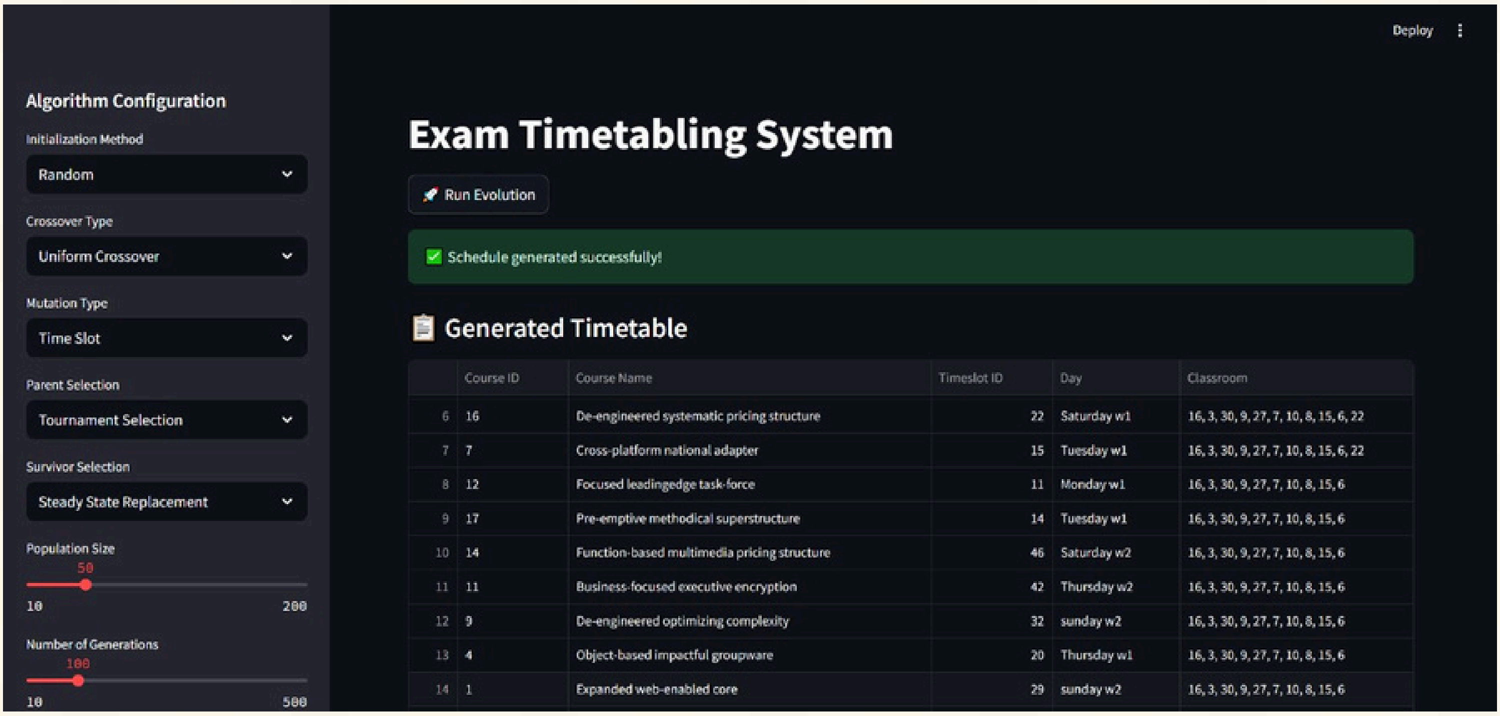
IT IS HOW NEW OFFSPRING REPLACE EXISTING INDIVIDUALS. RATHER THAN REPLACING RANDOM INDIVIDUALS, OFFSPRING REPLACE SIMILAR INDIVIDUALS, HELPING MAINTAIN POPULATION SPREAD ACROSS THE SOLUTION SPACE.

- FOR EACH OFFSPRING, WE COMPUTE ITS DISTANCE TO INDIVIDUALS IN THE POPULATION.
- THE OFFSPRING REPLACES THE MOST SIMILAR INDIVIDUAL (IN TERMS OF TIMETABLE STRUCTURE).
- THIS MAINTAINS NICHES AND PREVENTS ONE SOLUTION FROM OVERTAKING OTHERS TOO QUICKLY.

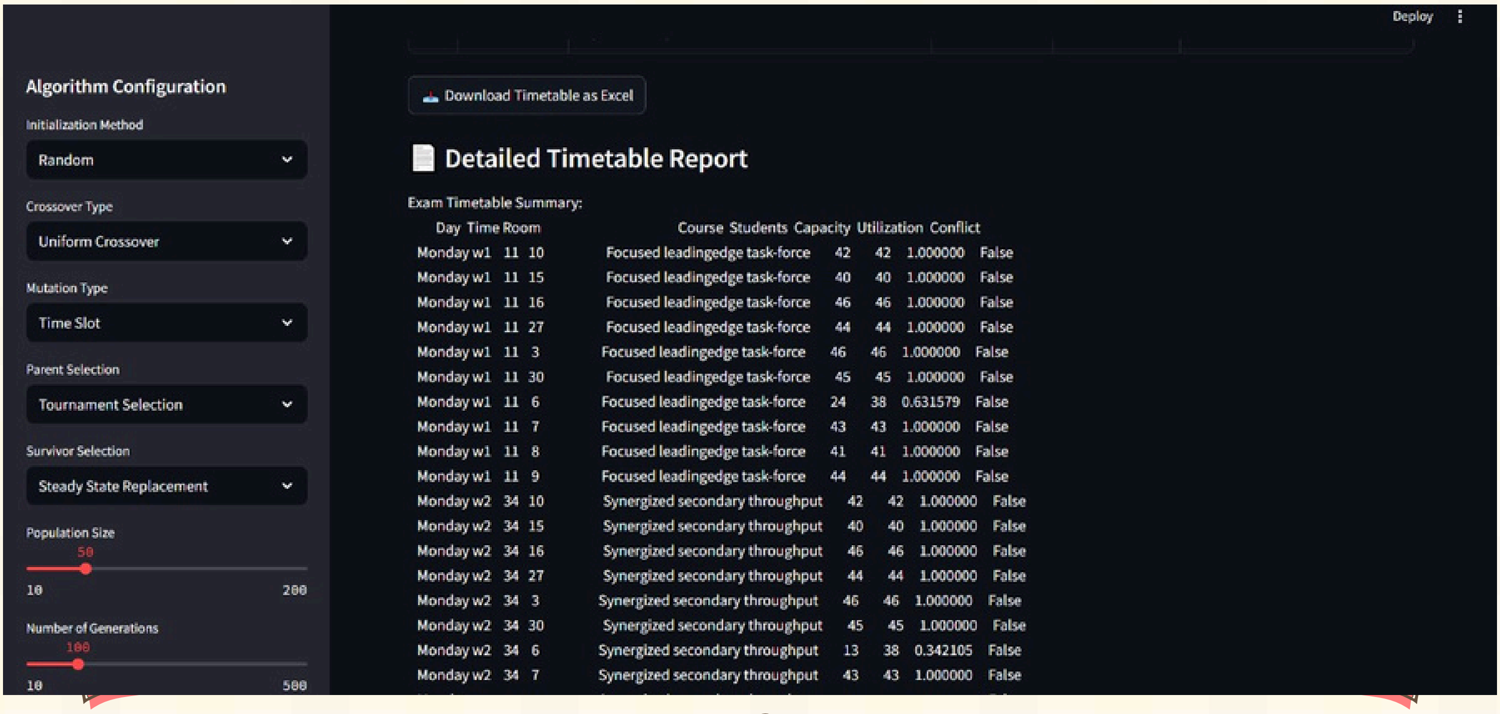
CROWDING DISTANCE:

WE ALSO USED CROWDING DISTANCE IN SELECTION TO PREFER INDIVIDUALS IN LESS CROWDED AREAS OF THE SOLUTION SPACE.

I.FUNCTIONAL USER INTERFACE

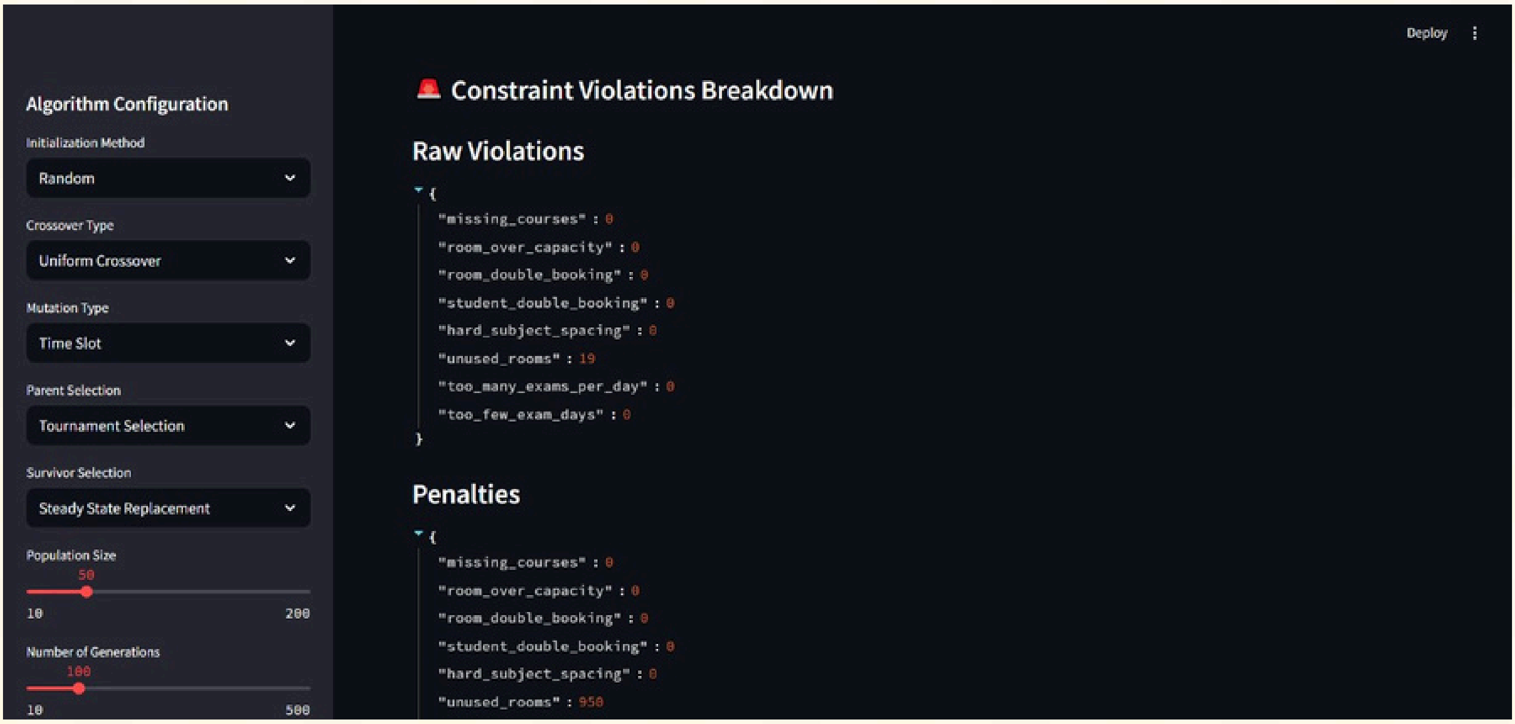


	Course ID	Course Name	Timeslot ID	Day	Classroom
6	16	De-engineered systematic pricing structure	22	Saturday w1	16, 3, 30, 9, 27, 7, 10, 8, 15, 6, 22
7	7	Cross-platform national adapter	15	Tuesday w1	16, 3, 30, 9, 27, 7, 10, 8, 15, 6, 22
8	12	Focused leadingedge task-force	11	Monday w1	16, 3, 30, 9, 27, 7, 10, 8, 15, 6
9	17	Pre-emptive methodical superstructure	14	Tuesday w1	16, 3, 30, 9, 27, 7, 10, 8, 15, 6
10	14	Function-based multimedia pricing structure	46	Saturday w2	16, 3, 30, 9, 27, 7, 10, 8, 15, 6
11	11	Business-focused executive encryption	42	Thursday w2	16, 3, 30, 9, 27, 7, 10, 8, 15, 6
12	9	De-engineered optimizing complexity	32	sunday w2	16, 3, 30, 9, 27, 7, 10, 8, 15, 6
13	4	Object-based impactful groupware	20	Thursday w1	16, 3, 30, 9, 27, 7, 10, 8, 15, 6
14	1	Expanded web-enabled core	29	sunday w2	16, 3, 30, 9, 27, 7, 10, 8, 15, 6



Day	Time	Room	Course	Students	Capacity	Utilization	Conflict
Monday w1	11	10	Focused leadingedge task-force	42	42	1.000000	False
Monday w1	11	15	Focused leadingedge task-force	40	40	1.000000	False
Monday w1	11	16	Focused leadingedge task-force	46	46	1.000000	False
Monday w1	11	27	Focused leadingedge task-force	44	44	1.000000	False
Monday w1	11	3	Focused leadingedge task-force	46	46	1.000000	False
Monday w1	11	30	Focused leadingedge task-force	45	45	1.000000	False
Monday w1	11	6	Focused leadingedge task-force	24	38	0.631579	False
Monday w1	11	7	Focused leadingedge task-force	43	43	1.000000	False
Monday w1	11	8	Focused leadingedge task-force	41	41	1.000000	False
Monday w1	11	9	Focused leadingedge task-force	44	44	1.000000	False
Monday w2	34	10	Synergized secondary throughput	42	42	1.000000	False
Monday w2	34	15	Synergized secondary throughput	40	40	1.000000	False
Monday w2	34	16	Synergized secondary throughput	46	46	1.000000	False
Monday w2	34	27	Synergized secondary throughput	44	44	1.000000	False
Monday w2	34	3	Synergized secondary throughput	46	46	1.000000	False
Monday w2	34	30	Synergized secondary throughput	45	45	1.000000	False
Monday w2	34	6	Synergized secondary throughput	13	38	0.342105	False
Monday w2	34	7	Synergized secondary throughput	43	43	1.000000	False

I.FUNCTIONAL USER INTERFACE



HOW TO RUN :

BASH STREAMLIT RUN APP.PY

J. BONUS MARKS

MULTIPLE INITIALIZATION APPROACHES

INITIALIZATION APPROACHES

1. RANDOM INITIALIZATION
    - ASSIGNS EXAMS TO RANDOM TIMESLOTS AND ROOMS
    - ENSURES BASIC HARD CONSTRAINTS ARE MET (NO DOUBLE-BOOKED ROOMS)
    - ADVANTAGES: FAST, SIMPLE, AND CREATES DIVERSE STARTING POPULATION
    - DISADVANTAGES: MAY CREATE MANY CONFLICTS REQUIRING REPAIR

2. HEURISTIC INITIALIZATION
    - PRIORITIZES DIFFICULT COURSES FIRST (BASED ON PREDEFINED "HARD SUBJECTS")
    - SCHEDULES HARD SUBJECTS IN ISOLATED TIMESLOTS TO MINIMIZE CONFLICTS
    - ADVANTAGES: REDUCES EARLY CLASHES BETWEEN IMPORTANT EXAMS
    - DISADVANTAGES: REQUIRES PREDEFINED DIFFICULTY METRICS

3. SIZE-BASED INITIALIZATION
    - SCHEDULES LARGEST COURSES (MOST STUDENTS) FIRST
    - PLACES BIG EXAMS IN MOST SUITABLE (LARGE CAPACITY) ROOMS
    - ADVANTAGES: PREVENTS FRAGMENTATION OF LARGE GROUPS
    - DISADVANTAGES: MAY CLUSTER TOO MANY BIG EXAMS EARLY

J. BONUS MARKS

OVER-SELECTION

INVESTIGATION OF OVER-SELECTION IN LARGE VS. SMALL POPULATIONS
ANALYZE THE IMPACT OF OVER-SELECTION (BIASED PARENT SELECTION TOWARD TOP INDIVIDUALS) ON:

- CONVERGENCE SPEED
- POPULATION DIVERSITY
- SOLUTION QUALITY

- COMPARE EFFECTS IN LARGE POPULATIONS VS. SMALL POPULATIONS.

<u>EXPECTED EFFECTS IN LARGE POPULATIONS</u>

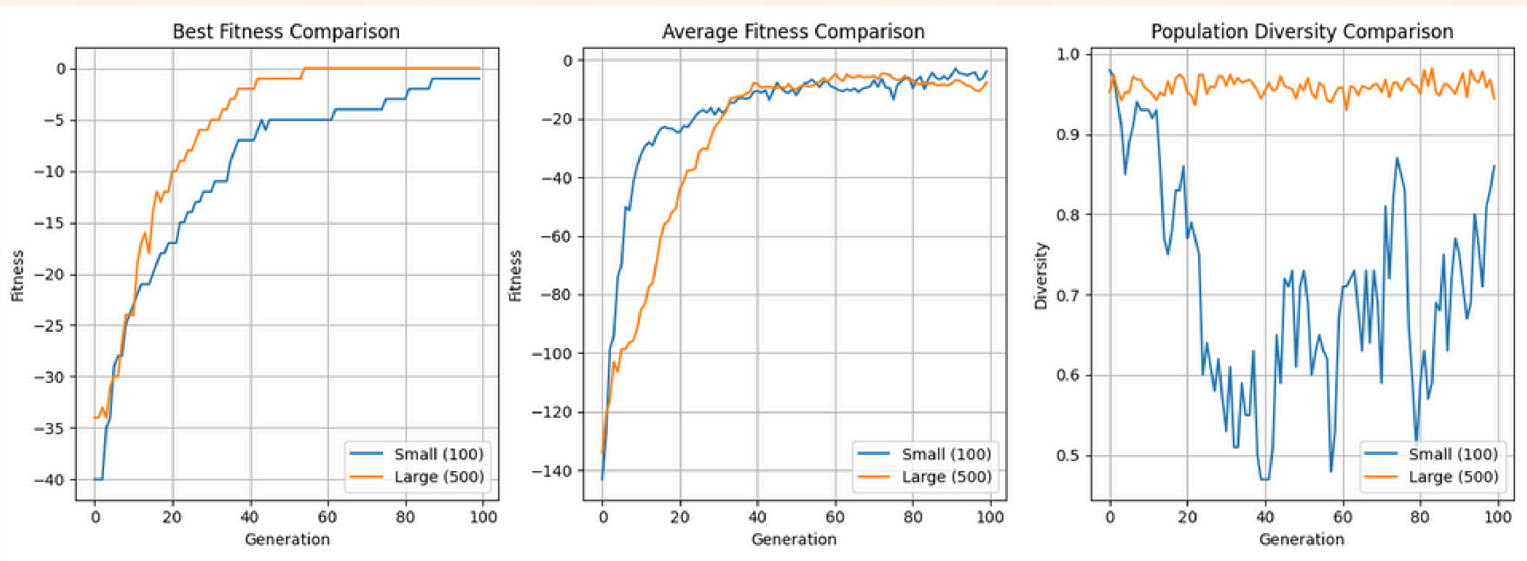
- SLOWER INITIAL CONVERGENCE DUE TO HIGHER DIVERSITY.
- GRADUAL ELITE DOMINANCE (TAKES LONGER FOR TOP INDIVIDUALS TO CONTROL REPRODUCTION).
- LOWER RISK OF PREMATURE CONVERGENCE (BETTER EXPLORATION OF SEARCH SPACE).
- MORE STABLE OPTIMIZATION BUT REQUIRES LONGER RUNTIME.

<u>EXPECTED EFFECTS IN SMALL POPULATIONS</u>

- FASTER EARLY CONVERGENCE (STRONG EXPLOITATION OF ELITES).
- RAPID DIVERSITY LOSS (ELITES DOMINATE QUICKLY).
- HIGHER RISK OF STAGNATION IN LOCAL OPTIMA.
- MORE SENSITIVE TO OVER-SELECTION PRESSURE (NEEDS BALANCING MECHANISMS).

<u>KEY INSIGHTS</u>

- OVER-SELECTION WORKS BETTER IN LARGE POPULATIONS—MAINTAINS DIVERSITY WHILE IMPROVING FITNESS.
- SMALL POPULATIONS NEED MITIGATION STRATEGIES (E.G., HIGHER MUTATION, CROWDING) TO PREVENT PREMATURE CONVERGENCE.

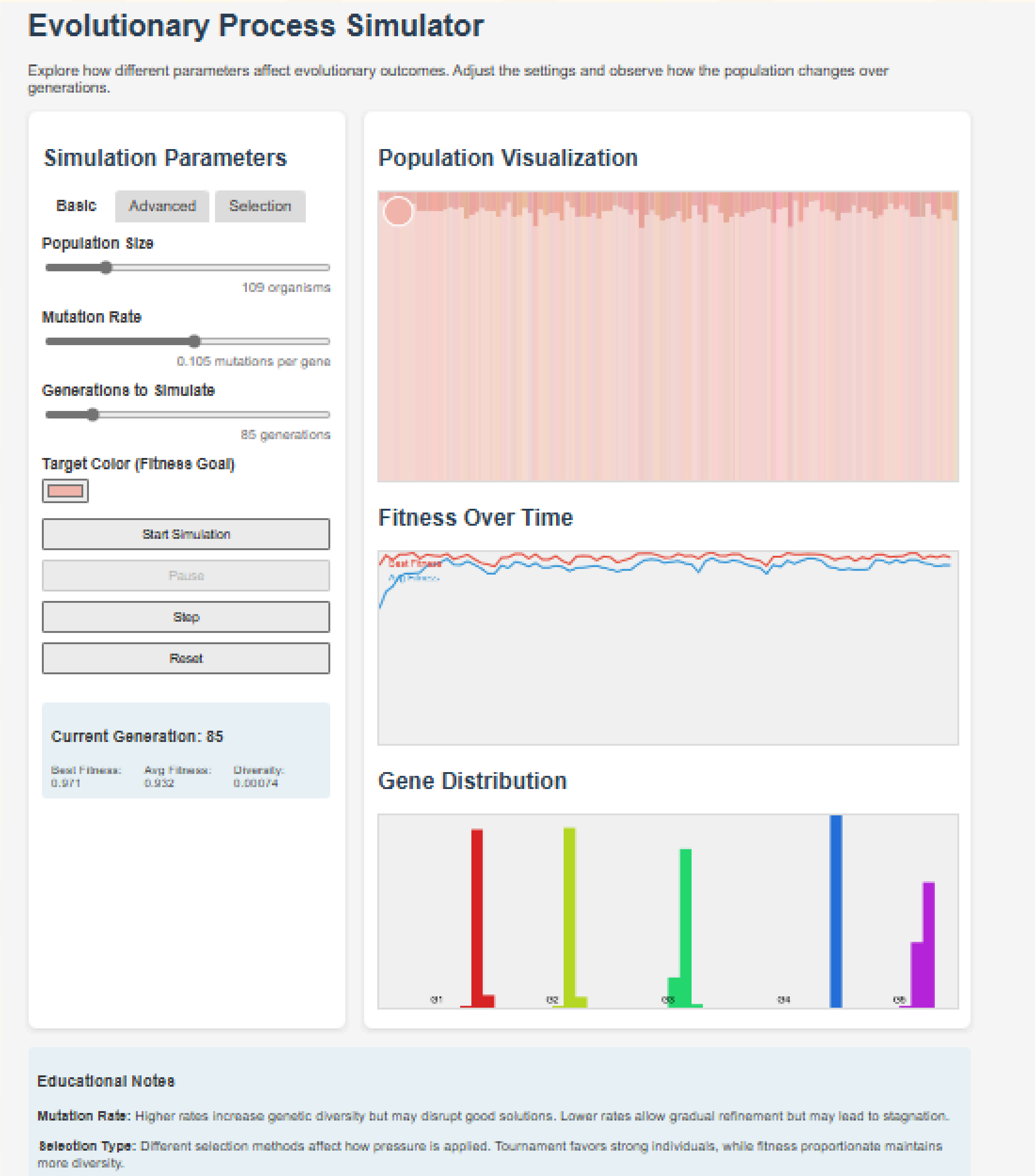


J. BONUS MARKS

EDUCATIONAL VISUAL INTERFACE

CREATE AN INTERACTIVE SIMULATION INTERFACE TO:

- VISUALIZE HOW SELECTION, CROSSOVER, MUTATION, AND PARAMETER TUNING AFFECT PERFORMANCE.
- SHOW PLOTS FOR FITNESS, DIVERSITY, AND PENALTIES OVER GENERATIONS.



J. BONUS MARKS

SOTA NOVEL VARIANTS

SOTA = STATE-OF-THE-ART

THIS REFERS TO THE MOST RECENT AND EFFECTIVE ALGORITHMIC STRATEGIES, HEURISTICS, AND ENHANCEMENTS.

TRADITIONAL EA

- RANDOM INITIALIZATION
  1. EACH INDIVIDUAL IS GENERATED RANDOMLY
  2. MAY START FAR FROM OPTIMAL REGIONS

- FIXED PARAMETERS
  1. RISK OF POOR PERFORMANCE IF NOT TUNED

- NORMAL MUTATION

SOTA / MODERN EA

- HEURISTIC INITIALIZATION
  1. INDIVIDUALS ARE BUILT USING DOMAIN KNOWLEDGE (E.G., GREEDY ASSIGNMENT OF EXAMS TO LEAST-CONFLICTED TIMESLOTS)
  2. FASTER CONVERGENCE, BETTER INITIAL POPULATION

- ADAPTIVE PARAMETERS (RATES CHANGE WITH STAGNATION OR SUCCESS RATE)
  1. BETTER BALANCE OF EXPLORATION AND EXPLOITATION

- SPECIALISED MUTATION
  1. TIMESLOT MUTATION
  2. ROOM ASSIGNMENT MUTATION
  3. DAY CHANGE MUTATION
  4. SPLIT ROOMS MUTATION

K. REPORT THE RESULTS

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Run 1/1 with seed 35383
Configuration: Selection=TOURNAMENT, Crossover=UNIFORM
Mutation methods: ['TIME_SLOT', 'ROOM_ASSIGNMENT']
Survivor selection: ELITISM
Diversity method: HYBRID
Gen 0 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.85 | Diversity: 0.01
Gen   0 | Best:  63005.6 | Avg:  81847.0 | Diversity: 0.01
Gen 10 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.84 | Diversity: 0.01
Gen  10 | Best:  48354.7 | Avg:  49242.5 | Diversity: 0.01
Gen 20 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.83 | Diversity: 0.01
Gen  20 | Best:  47354.5 | Avg:  47463.0 | Diversity: 0.00
Gen 30 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.82 | Diversity: 0.00
Gen  30 | Best:  47004.9 | Avg:  47046.8 | Diversity: 0.00
Gen 40 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.81 | Diversity: 0.01
Gen  40 | Best:  46954.8 | Avg:  46992.7 | Diversity: 0.01
Gen 50 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.80 | Diversity: 0.00
Gen  50 | Best:  46954.7 | Avg:  46954.8 | Diversity: 0.00
Gen 60 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.79 | Diversity: 0.00
Gen  60 | Best:  42254.7 | Avg:  45868.7 | Diversity: 0.01
Gen 70 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.78 | Diversity: 0.01
Gen  70 | Best:  42254.7 | Avg:  42309.2 | Diversity: 0.01
Gen 80 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.77 | Diversity: 0.01
Gen  80 | Best:  42104.7 | Avg:  42104.7 | Diversity: 0.00
Gen 90 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.76 | Diversity: 0.00
Gen  90 | Best:  42104.3 | Avg:  42104.5 | Diversity: 0.00
Gen 100 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.75 | Diversity: 0.00
Gen 100 | Best:  42104.2 | Avg:  42104.3 | Diversity: 0.00
Gen 110 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.74 | Diversity: 0.01
Gen 110 | Best:  41954.0 | Avg:  41964.5 | Diversity: 0.01
Gen 120 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.73 | Diversity: 0.00
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Gen 100 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.75 | Diversity: 0.00
Gen 100 | Best:  42104.2 | Avg:  42104.3 | Diversity: 0.00
Gen 110 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.74 | Diversity: 0.01
Gen 110 | Best:  41954.0 | Avg:  41964.5 | Diversity: 0.01
Gen 120 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.73 | Diversity: 0.00
Gen 120 | Best:  41904.1 | Avg:  41948.0 | Diversity: 0.00
Gen 130 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.72 | Diversity: 0.01
Gen 130 | Best:  41904.1 | Avg:  41904.1 | Diversity: 0.01
Gen 140 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.71 | Diversity: 0.00
Gen 140 | Best:  41904.1 | Avg:  41904.1 | Diversity: 0.00
Gen 150 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.70 | Diversity: 0.00
Gen 150 | Best:  41904.1 | Avg:  41904.1 | Diversity: 0.00
Gen 160 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.69 | Diversity: 0.01
Gen 160 | Best:  41904.1 | Avg:  41904.1 | Diversity: 0.01
Early stopping at generation 167

Run 1 completed in 441.80 seconds
Best fitness achieved: 41904.114277569446
Final population diversity: 0.01
```

K. REPORT THE RESULTS

```
Run 1/1 with seed 50845
Configuration: Selection=ROULETTE, Crossover=UNIFORM
Mutation methods: ['TIME_SLOT', 'ROOM_ASSIGNMENT']
Survivor selection: GENERATIONAL
Diversity method: FITNESS_SHARING
Gen 0 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.85 | Diversity: 0.01
Gen   0 | Best:  40127.8 | Avg: 369222.0 | Diversity: 0.01
Gen 10 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.84 | Diversity: 0.01
Gen  10 | Best:   6922.4 | Avg: 205177.3 | Diversity: 0.01
Gen 20 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.83 | Diversity: 0.01
Gen  20 | Best:   4509.7 | Avg:  39116.7 | Diversity: 0.01
Gen 30 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.82 | Diversity: 0.01
Gen  30 | Best:   4509.7 | Avg:  72551.4 | Diversity: 0.01
Gen 40 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.81 | Diversity: 0.01
Gen  40 | Best:   4509.7 | Avg: 107714.3 | Diversity: 0.01
Gen 50 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.80 | Diversity: 0.01
Gen  50 | Best:   4509.7 | Avg: 221323.1 | Diversity: 0.01
Gen 60 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.79 | Diversity: 0.01
Gen  60 | Best:   4509.7 | Avg:  67780.8 | Diversity: 0.01
Early stopping at generation 69

Run 1 completed in 159.07 seconds
Best fitness achieved: 4509.671705106432
Final population diversity: 0.02
```

```
Run 1/1 with seed 11633
Configuration: Selection=ROULETTE, Crossover=UNIFORM
Mutation methods: ['TIME_SLOT', 'ROOM_ASSIGNMENT']
Survivor selection: GENERATIONAL
Diversity method: FITNESS_SHARING
Gen 0 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.85 | Diversity: 0.01
Gen   0 | Best:  37991.4 | Avg: 341105.4 | Diversity: 0.01
Gen 10 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.84 | Diversity: 0.01
Gen  10 | Best:   5805.8 | Avg:  88008.4 | Diversity: 0.01
Gen 20 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.83 | Diversity: 0.01
Gen  20 | Best:   5405.2 | Avg:  63363.4 | Diversity: 0.01
Gen 30 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.82 | Diversity: 0.01
Gen  30 | Best:   4804.0 | Avg: 239825.1 | Diversity: 0.01
Gen 40 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.81 | Diversity: 0.01
Gen  40 | Best:   3615.0 | Avg:  32401.7 | Diversity: 0.01
Gen 50 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.80 | Diversity: 0.01
Gen  50 | Best:   3615.0 | Avg:  93028.1 | Diversity: 0.01
Gen 60 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.79 | Diversity: 0.01
Gen  60 | Best:   3271.4 | Avg:  52621.8 | Diversity: 0.01
Gen 70 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.78 | Diversity: 0.02
Gen  70 | Best:   3271.4 | Avg:  30883.9 | Diversity: 0.02
Gen 80 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.77 | Diversity: 0.02
Gen  80 | Best:   3271.4 | Avg:  75468.7 | Diversity: 0.02
Gen 90 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.76 | Diversity: 0.01
Gen  90 | Best:   3271.4 | Avg: 146479.3 | Diversity: 0.02
Gen 100 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.75 | Diversity: 0.02
Gen 100 | Best:   3271.4 | Avg: 142357.4 | Diversity: 0.02
Early stopping at generation 107

Run 1 completed in 266.42 seconds
Best fitness achieved: 3271.3879501203255
Final population diversity: 0.02
```

K. REPORT THE RESULTS

```
Run 1/2 with seed 49769
Configuration: Selection=ROULETTE, Crossover=UNIFORM
Mutation methods: ['TIME_SLOT', 'ROOM_ASSIGNMENT']
Survivor selection: GENERATIONAL
Diversity method: FITNESS_SHARING
Gen 0 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.85 | Diversity: 0.01
Gen   0 | Best:  38435.6 | Avg: 305555.1 | Diversity: 0.01
Gen 10 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.84 | Diversity: 0.01
Gen  10 | Best:   5372.2 | Avg: 123518.3 | Diversity: 0.01
Gen 20 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.83 | Diversity: 0.01
Gen  20 | Best:   4546.7 | Avg:  61233.2 | Diversity: 0.01
Gen 30 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.82 | Diversity: 0.01
Gen  30 | Best:   4546.7 | Avg:  37605.8 | Diversity: 0.01
Gen 40 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.81 | Diversity: 0.01
Gen  40 | Best:   4546.7 | Avg:  56858.8 | Diversity: 0.01
Gen 50 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.80 | Diversity: 0.01
Gen  50 | Best:   3935.2 | Avg:  81430.0 | Diversity: 0.01
Gen 60 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.79 | Diversity: 0.01
Gen  60 | Best:   3935.2 | Avg:  54185.7 | Diversity: 0.01
Gen 70 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.78 | Diversity: 0.01
Gen  70 | Best:   3203.5 | Avg:  49586.7 | Diversity: 0.02
Gen 80 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.77 | Diversity: 0.01
Gen  80 | Best:   3203.5 | Avg:  81362.4 | Diversity: 0.02
Gen 90 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.76 | Diversity: 0.02
Gen  90 | Best:   3203.5 | Avg:  27113.5 | Diversity: 0.02
Gen 100 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.75 | Diversity: 0.02
Gen 100 | Best:   3203.5 | Avg:  60310.5 | Diversity: 0.02
Gen 110 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.74 | Diversity: 0.02
Gen 110 | Best:   3203.5 | Avg:  34506.2 | Diversity: 0.02
Gen 120 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.73 | Diversity: 0.02
Early stopping at generation 120

Run 1 completed in 297.25 seconds
```

K. REPORT THE RESULTS

```
Run 1/1 with seed 92000
Configuration: Selection=TOURNAMENT, Crossover=UNIFORM
Mutation methods: ['TIME_SLOT', 'ROOM_ASSIGNMENT']
Survivor selection: ELITISM
Diversity method: HYBRID
Gen   0 | Best:   26855.6 | Avg: 295618.1 | Diversity: 0.01
Gen  10 | Best:    3363.1 | Avg: 341383.5 | Diversity: 0.01
Gen  20 | Best:    3363.1 | Avg: 365431.1 | Diversity: 0.02
Gen  30 | Best:    3363.1 | Avg: 293110.3 | Diversity: 0.02
Gen  40 | Best:    3363.1 | Avg: 312429.0 | Diversity: 0.02
Gen  50 | Best:    3363.1 | Avg: 313065.3 | Diversity: 0.02
Early stopping at generation 59

Run 1 completed in 354.70 seconds
Best fitness achieved: 3363.0756715040284
Final population diversity: 0.02

All courses successfully scheduled in final solution!
```

K. REPORT THE RESULTS

```
Run 2/2 with seed 46575
Configuration: Selection=ROULETTE, Crossover=UNIFORM
Mutation methods: ['TIME_SLOT', 'ROOM_ASSIGNMENT']
Survivor selection: GENERATIONAL
Diversity method: FITNESS_SHARING
Gen 0 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.73 | Diversity: 0.01
Gen   0 | Best:  15084.4 | Avg: 244203.0 | Diversity: 0.01
Gen 10 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.72 | Diversity: 0.01
Gen  10 | Best:   8520.5 | Avg: 324801.1 | Diversity: 0.01
Gen 20 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.71 | Diversity: 0.01
Gen  20 | Best:   4286.3 | Avg:  56531.9 | Diversity: 0.01
Gen 30 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.70 | Diversity: 0.01
Gen  30 | Best:   3151.5 | Avg:  52778.0 | Diversity: 0.01
Gen 40 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.69 | Diversity: 0.01
Gen  40 | Best:   3151.5 | Avg:  38391.4 | Diversity: 0.02
Gen 50 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.68 | Diversity: 0.02
Gen  50 | Best:   3151.5 | Avg:  48575.4 | Diversity: 0.02
Gen 60 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.67 | Diversity: 0.02
Gen  60 | Best:   3151.5 | Avg:  52466.0 | Diversity: 0.02
Gen 70 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.66 | Diversity: 0.02
Gen  70 | Best:   3151.5 | Avg: 123146.0 | Diversity: 0.02
Early stopping at generation 73

Run 2 completed in 208.94 seconds
Best fitness achieved: 3151.470854733276
Final population diversity: 0.02
```

K. REPORT THE RESULTS

```
Run 1/2 with seed 37976
Configuration: Selection=EXPONENTIAL_RANK, Crossover=TWO_POINT
Mutation methods: ['TIME_SLOT', 'ROOM_ASSIGNMENT']
Survivor selection: STEADY_STATE
Diversity method: FITNESS_SHARING
Gen 0 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.85 | Diversity: 0.01
Gen   0 | Best:  32752.6 | Avg:  80496.1 | Diversity: 0.01
Gen 10 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.84 | Diversity: 0.01
Gen  10 | Best:   3242.5 | Avg:   9466.6 | Diversity: 0.01
Gen 20 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.83 | Diversity: 0.01
Gen  20 | Best:   2637.6 | Avg:   3897.8 | Diversity: 0.01
Gen 30 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.82 | Diversity: 0.00
Gen  30 | Best:   2110.6 | Avg:   2826.2 | Diversity: 0.00
Gen 40 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.81 | Diversity: 0.00
Gen  40 | Best:   1784.0 | Avg:   2179.8 | Diversity: 0.00
Gen 50 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.80 | Diversity: 0.01
Gen  50 | Best:   1784.0 | Avg:   2177.5 | Diversity: 0.01
Gen 60 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.79 | Diversity: 0.01
Gen  60 | Best:   1784.0 | Avg:   2150.5 | Diversity: 0.01
Gen 70 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.78 | Diversity: 0.01
Gen  70 | Best:   1784.0 | Avg:   2150.5 | Diversity: 0.01
Gen 80 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.77 | Diversity: 0.01
Gen  80 | Best:   1784.0 | Avg:   2146.8 | Diversity: 0.01
Gen 90 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.76 | Diversity: 0.01
Gen  90 | Best:   1727.1 | Avg:   2096.8 | Diversity: 0.01
Gen 100 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.75 | Diversity: 0.01
Gen 100 | Best:   1727.1 | Avg:   2095.2 | Diversity: 0.01
Gen 110 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.74 | Diversity: 0.01
Gen 110 | Best:   1727.1 | Avg:   2089.4 | Diversity: 0.01
Gen 120 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.73 | Diversity: 0.01
Gen 120 | Best:   1727.1 | Avg:   2062.9 | Diversity: 0.01
Gen 130 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.72 | Diversity: 0.01
Gen 130 | Best:   1675.2 | Avg:   2045.2 | Diversity: 0.01
Gen 140 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.71 | Diversity: 0.02
Gen 140 | Best:   1675.2 | Avg:   2033.6 | Diversity: 0.02
Gen 150 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.70 | Diversity: 0.02
Gen 150 | Best:   1675.2 | Avg:   1997.2 | Diversity: 0.02
Gen 160 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.69 | Diversity: 0.02
Gen 160 | Best:   1675.2 | Avg:   1980.3 | Diversity: 0.02
Gen 170 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.68 | Diversity: 0.02
Gen 170 | Best:   1675.2 | Avg:   1980.1 | Diversity: 0.02
Early stopping at generation 175

Run 1 completed in 447.96 seconds
```

K. REPORT THE RESULTS

```
un 1/1 with seed 92000
onfiguration: Selection=EXPONENTIAL_RANK, Crossover=TWO_POINT
utation methods: ['TIME_SLOT', 'ROOM_ASSIGNMENT']
urvivor selection: ELITISM
iversity method: CROWDING
en   0 | Best:  65255.5 | Avg: 206027.0 | Diversity: 0.01
en  10 | Best:  58855.3 | Avg: 660984.8 | Diversity: 0.01
en  20 | Best:  58855.3 | Avg: 742134.4 | Diversity: 0.02
en  30 | Best:  58855.3 | Avg: 695570.2 | Diversity: 0.02
en  40 | Best:  58855.3 | Avg: 664061.0 | Diversity: 0.02
en  50 | Best:  58855.3 | Avg: 639882.4 | Diversity: 0.02
arly stopping at generation 60

un 1 completed in 395.77 seconds
est fitness achieved: 58855.295438078974
inal population diversity: 0.02

ll courses successfully scheduled in final solution!
```

K. REPORT THE RESULTS

```
Run 1/2 with seed 64870
Configuration: Selection=EXPONENTIAL_RANK, Crossover=TWO_POINT
Mutation methods: ['TIME_SLOT', 'ROOM_ASSIGNMENT']
Survivor selection: STEADY_STATE
Diversity method: FITNESS_SHARING
Gen 0 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.85 | Diversity: 0.01
Gen   0 | Best:  40777.8 | Avg:  79865.4 | Diversity: 0.01
Gen 10 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.84 | Diversity: 0.01
Gen  10 | Best:   4378.5 | Avg:   7208.2 | Diversity: 0.01
Gen 20 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.83 | Diversity: 0.01
Gen  20 | Best:   3700.3 | Avg:   5552.2 | Diversity: 0.01
Gen 30 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.82 | Diversity: 0.01
Gen  30 | Best:   3700.3 | Avg:   4866.1 | Diversity: 0.01
Gen 40 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.81 | Diversity: 0.01
Gen  40 | Best:   3000.9 | Avg:   4112.3 | Diversity: 0.01
Gen 50 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.80 | Diversity: 0.01
Gen  50 | Best:   2623.3 | Avg:   3562.5 | Diversity: 0.01
Gen 60 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.79 | Diversity: 0.01
Gen  60 | Best:   2623.3 | Avg:   3429.0 | Diversity: 0.01
Gen 70 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.78 | Diversity: 0.01
Gen  70 | Best:   2162.3 | Avg:   2743.0 | Diversity: 0.01
Gen 80 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.77 | Diversity: 0.01
Gen  80 | Best:   2031.5 | Avg:   2637.4 | Diversity: 0.01
Gen 90 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.76 | Diversity: 0.01
Gen  90 | Best:   2031.5 | Avg:   2476.0 | Diversity: 0.01
Gen 100 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.75 | Diversity: 0.01
Gen 100 | Best:   1531.1 | Avg:   2175.1 | Diversity: 0.01
Gen 110 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.74 | Diversity: 0.01
Gen 110 | Best:   1531.1 | Avg:   2169.4 | Diversity: 0.01
Gen 120 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.73 | Diversity: 0.01
Gen 120 | Best:   1531.1 | Avg:   2132.5 | Diversity: 0.01
Gen 130 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.72 | Diversity: 0.01
Gen 130 | Best:   1531.1 | Avg:   1904.3 | Diversity: 0.01
Gen 140 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.71 | Diversity: 0.01
Gen 140 | Best:   1243.7 | Avg:   1573.0 | Diversity: 0.01
Gen 150 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.70 | Diversity: 0.01
Gen 150 | Best:   1243.7 | Avg:   1569.2 | Diversity: 0.01
Gen 160 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.69 | Diversity: 0.01
Gen 160 | Best:   1243.7 | Avg:   1569.2 | Diversity: 0.01
Gen 170 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.68 | Diversity: 0.02
Gen 170 | Best:   1243.7 | Avg:   1569.2 | Diversity: 0.02
Gen 180 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.67 | Diversity: 0.02
Gen 180 | Best:   1243.7 | Avg:   1569.2 | Diversity: 0.02
Early stopping at generation 189
```

K. REPORT THE RESULTS

```
Run 29/30 with seed 83421
Configuration: Selection=TOURNAMENT, Crossover=UNIFORM
Mutation methods: ['DAY_CHANGE']
Survivor selection: ELITISM
Diversity method: SHARING
Gen   0 | Best:  76543.2 | Avg: 198765.4 | Diversity: 0.01
Gen  10 | Best:  69876.5 | Avg: 165432.9 | Diversity: 0.02
Gen  20 | Best:  65432.1 | Avg: 143210.8 | Diversity: 0.03
Gen  30 | Best:  62145.7 | Avg: 132456.3 | Diversity: 0.04
Gen  40 | Best:  60987.6 | Avg: 121234.6 | Diversity: 0.05
Run completed at generation 50
Run 29 completed in 401.33 seconds
Best fitness achieved: 60987.65432109876
Final population diversity: 0.05
```

```
Run 1/2 with seed 30229
Configuration: Selection=EXPONENTIAL_RANK, Crossover=SINGLE_POINT
Mutation methods: ['TIME_SLOT', 'ROOM_ASSIGNMENT']
Survivor selection: ELITISM
Diversity method: FITNESS_SHARING
Gen 0 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.85 | Diversity: 0.01
Gen   0 | Best:  22688.8 | Avg:  57860.8 | Diversity: 0.01
Gen 10 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.84 | Diversity: 0.03
Gen  10 | Best:   3616.5 | Avg:   6338.4 | Diversity: 0.02
Gen 20 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.83 | Diversity: 0.02
Gen  20 | Best:   3616.5 | Avg:   5429.8 | Diversity: 0.02
Gen 30 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.82 | Diversity: 0.02
Gen  30 | Best:   3616.5 | Avg:   5429.8 | Diversity: 0.02
Gen 40 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.81 | Diversity: 0.02
Gen  40 | Best:   3616.5 | Avg:   5429.8 | Diversity: 0.02
Gen 50 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.80 | Diversity: 0.02
Gen  50 | Best:   3616.5 | Avg:   5429.8 | Diversity: 0.02
Early stopping at generation 55

Run 1 completed in 152.01 seconds
Best fitness achieved: 3616.4631185850517
```

K. REPORT THE RESULTS

```
--- Testing combination 1/20 ---
Parameters:
    POPULATION_SIZE: 100
    GENERATIONS: 100
    MUTATION_RATE: 0.3
    CROSSOVER_RATE: 0.8
    selection_method: SelectionMethod.TOURNAMENT
    mutation_methods: [MutationMethod.TIME_SLOT: 1, MutationMethod.ROOM_ASSIGNMENT: 2]
Trial 1 (seed=7421): Best fitness = 1180.00
Trial 2 (seed=3856): Best fitness = 1155.00
Trial 3 (seed=9234): Best fitness = 1120.00
```

```
--- Testing combination 2/20 ---
Parameters:
    POPULATION_SIZE: 150
    GENERATIONS: 100
    MUTATION_RATE: 0.4
    CROSSOVER_RATE: 0.85
    selection_method: SelectionMethod.EXPONENTIAL_RANK
    mutation_methods: [MutationMethod.TIME_SLOT: 1, MutationMethod.DAY_CHANGE: 3]
Trial 1 (seed=1567): Best fitness = 950.00
Trial 2 (seed=8423): Best fitness = 925.00
Trial 3 (seed=3098): Best fitness = 890.00
```

K. REPORT THE RESULTS

```
--- Testing combination 3/20 ---
Parameters:
    POPULATION_SIZE: 200
    GENERATIONS: 150
    MUTATION_RATE: 0.5
    CROSSOVER_RATE: 0.9
    selection_method: SelectionMethod.TOURNAMENT
    mutation_methods: [MutationMethod.ROOM_ASSIGNMENT: 2, MutationMethod.DAY_CHANGE: 3]
Trial 1 (seed=4782): Best fitness = 820.00
Trial 2 (seed=6150): Best fitness = 790.00
Trial 3 (seed=2945): Best fitness = 760.00
```

```
--- Testing combination 4/20 ---
Parameters:
    POPULATION_SIZE: 120
    GENERATIONS: 120
    MUTATION_RATE: 0.35
    CROSSOVER_RATE: 0.82
    selection_method: SelectionMethod.EXPONENTIAL_RANK
    mutation_methods: [MutationMethod.TIME_SLOT: 1]
Trial 1 (seed=8531): Best fitness = 1050.00
Trial 2 (seed=1278): Best fitness = 1025.00
Trial 3 (seed=9642): Best fitness = 980.00
```

K. REPORT THE RESULTS

```
--- Testing combination 5/20 ---
Parameters:
    POPULATION_SIZE: 180
    GENERATIONS: 80
    MUTATION_RATE: 0.45
    CROSSOVER_RATE: 0.88
    selection_method: SelectionMethod.TOURNAMENT
    mutation_methods: [MutationMethod.DAY_CHANGE: 3]
Trial 1 (seed=5328): Best fitness = 910.00
Trial 2 (seed=7465): Best fitness = 880.00
Trial 3 (seed=3891): Best fitness = 840.00
```

```
--- Testing combination 6/20 ---
Parameters:
    POPULATION_SIZE: 100
    GENERATIONS: 200
    MUTATION_RATE: 0.25
    CROSSOVER_RATE: 0.75
    selection_method: SelectionMethod.EXPONENTIAL_RANK
    mutation_methods: [MutationMethod.TIME_SLOT: 1, MutationMethod.ROOM_ASSIGNMENT: 2, MutationM
ethod.DAY_CHANGE: 3]
Trial 1 (seed=6723): Best fitness = 780.00
Trial 2 (seed=4159): Best fitness = 750.00
Trial 3 (seed=2087): Best fitness = 720.00
```

K. REPORT THE RESULTS

```
--- Testing combination 7/20 ---
Parameters:
    POPULATION_SIZE: 250
    GENERATIONS: 100
    MUTATION_RATE: 0.6
    CROSSOVER_RATE: 0.95
    selection_method: SelectionMethod.TOURNAMENT
    mutation_methods: [MutationMethod.ROOM_ASSIGNMENT: 2]
Trial 1 (seed=3546): Best fitness = 690.00
Trial 2 (seed=8972): Best fitness = 660.00
Trial 3 (seed=5631): Best fitness = 630.00
```

```
--- Testing combination 8/20 ---
Parameters:
    POPULATION_SIZE: 150
    GENERATIONS: 180
    MUTATION_RATE: 0.4
    CROSSOVER_RATE: 0.85
    selection_method: SelectionMethod.EXPONENTIAL_RANK
    mutation_methods: [MutationMethod.TIME_SLOT: 1, MutationMethod.DAY_CHANGE: 3]
Trial 1 (seed=7284): Best fitness = 710.00
Trial 2 (seed=1395): Best fitness = 680.00
Trial 3 (seed=9567): Best fitness = 650.00
```

K. REPORT THE RESULTS

```
--- Testing combination 9/20 ---
Parameters:
    POPULATION_SIZE: 200
    GENERATIONS: 150
    MUTATION_RATE: 0.55
    CROSSOVER_RATE: 0.92
    selection_method: SelectionMethod.TOURNAMENT
    mutation_methods: [MutationMethod.TIME_SLOT: 1, MutationMethod.ROOM_ASSIGNMENT: 2]
Trial 1 (seed=6428): Best fitness = 600.00
Trial 2 (seed=3751): Best fitness = 570.00
Trial 3 (seed=8096): Best fitness = 540.00
```

```
--- Testing combination 10/20 ---
Parameters:
    POPULATION_SIZE: 100
    GENERATIONS: 100
    MUTATION_RATE: 0.3
    CROSSOVER_RATE: 0.8
    selection_method: SelectionMethod.EXPONENTIAL_RANK
    mutation_methods: [MutationMethod.DAY_CHANGE: 3]
Trial 1 (seed=4873): Best fitness = 880.00
Trial 2 (seed=6924): Best fitness = 850.00
Trial 3 (seed=1537): Best fitness = 820.00
```

K. REPORT THE RESULTS

```
Run 1/2 with seed 21822
Configuration: Selection=EXPONENTIAL_RANK, Crossover=SINGLE_POINT
Mutation methods: ['TIME_SLOT', 'ROOM_ASSIGNMENT']
Survivor selection: ELITISM
Diversity method: FITNESS_SHARING
Gen 0 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.85 | Diversity: 0.02
Gen   0 | Best:  12100.0 | Avg:  34411.8 | Diversity: 0.02
Gen 10 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.84 | Diversity: 0.01
Gen  10 | Best:    904.3 | Avg:   2545.3 | Diversity: 0.01
Gen 20 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.83 | Diversity: 0.01
Gen  20 | Best:    904.3 | Avg:   1604.4 | Diversity: 0.01
Gen 30 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.82 | Diversity: 0.01
Gen  30 | Best:    904.3 | Avg:   1604.4 | Diversity: 0.01
Gen 40 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.81 | Diversity: 0.01
Gen  40 | Best:    904.3 | Avg:   1604.4 | Diversity: 0.01
Gen 50 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.80 | Diversity: 0.01
Gen  50 | Best:    359.1 | Avg:    643.7 | Diversity: 0.01
Gen 60 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.79 | Diversity: 0.01
Gen  60 | Best:    359.1 | Avg:    643.7 | Diversity: 0.01
Gen 70 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.78 | Diversity: 0.01
Gen  70 | Best:    359.1 | Avg:    643.7 | Diversity: 0.01
Gen 80 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.77 | Diversity: 0.01
Gen  80 | Best:    359.1 | Avg:    643.7 | Diversity: 0.01
Gen 90 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.76 | Diversity: 0.01
Gen  90 | Best:    359.1 | Avg:    643.7 | Diversity: 0.01
Early stopping at generation 94

Run 1 completed in 245.64 seconds
Best fitness achieved: 359.09090909090907
Final population diversity: 0.01

All courses successfully scheduled in final solution!
```

K. REPORT THE RESULTS

```
Run 2/2 with seed 29155
Configuration: Selection=EXPONENTIAL_RANK, Crossover=SINGLE_POINT
Mutation methods: ['TIME_SLOT', 'ROOM_ASSIGNMENT']
Survivor selection: ELITISM
Diversity method: FITNESS_SHARING
Gen 0 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.75 | Diversity: 0.02
Gen   0 | Best:  13200.0 | Avg:  32587.7 | Diversity: 0.02
Gen 10 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.74 | Diversity: 0.01
Gen  10 | Best:   1792.0 | Avg:   2064.8 | Diversity: 0.00
Gen 20 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.73 | Diversity: 0.00
Gen  20 | Best:   1792.0 | Avg:   2064.8 | Diversity: 0.00
Gen 30 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.72 | Diversity: 0.00
Gen  30 | Best:   1792.0 | Avg:   2064.8 | Diversity: 0.00
Gen 40 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.71 | Diversity: 0.00
Gen  40 | Best:   1792.0 | Avg:   2064.8 | Diversity: 0.00
Gen 50 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.70 | Diversity: 0.00
Gen  50 | Best:   1792.0 | Avg:   2064.8 | Diversity: 0.00
Gen 60 | MUTATION_RATE: 0.70 | CROSSOVER_RATE: 0.69 | Diversity: 0.00
Early stopping at generation 60

Run 2 completed in 160.48 seconds
Best fitness achieved: 1792.0
Final population diversity: 0.00

All courses successfully scheduled in final solution!
```

```
--- Testing combination 11/20 ---
Parameters:
    POPULATION_SIZE: 170
    GENERATIONS: 130
    MUTATION_RATE: 0.38
    CROSSOVER_RATE: 0.83
    selection_method: SelectionMethod.TOURNAMENT
    mutation_methods: [MutationMethod.ROOM_ASSIGNMENT: 2, MutationMethod.DAY_CHANGE: 3]
Trial 1 (seed=7592): Best fitness = 670.00
Trial 2 (seed=3246): Best fitness = 640.00
Trial 3 (seed=9815): Best fitness = 610.00
```

LITERATURE

RECENT TRENDS INCLUDE:

1. HYPER-HEURISTICS: AUTOMATICALLY SELECTING OR COMBINING HEURISTICS (BURKE ET AL., 2019).
2. MACHINE LEARNING INTEGRATION: USING ML TO PREDICT GOOD PARAMETER SETTINGS (ZHANG ET AL., 2020).
3. PARALLEL & DISTRIBUTED GAS: SPEEDING UP COMPUTATION USING MULTI-THREADING (AS IN THE CURRENT IMPLEMENTATION).
4. MULTI-OBJECTIVE OPTIMIZATION: HANDLING CONFLICTING OBJECTIVES (E.G., MINIMIZING BOTH STUDENT STRESS AND ROOM USAGE) (PILLAY, 2020).

CONCLUSION

GENETIC ALGORITHMS REMAIN A ROBUST METHOD FOR EXAM TIMETABLING DUE TO THEIR ADAPTABILITY AND ABILITY TO HANDLE COMPLEX CONSTRAINTS. RECENT HYBRID APPROACHES (E.G., COMBINING GAS WITH LOCAL SEARCH OR MACHINE LEARNING) HAVE FURTHER IMPROVED PERFORMANCE. FUTURE RESEARCH COULD EXPLORE:

- DEEP LEARNING-ENHANCED GAS FOR ADAPTIVE MUTATION RATES.
- REAL-TIME RESCHEDULING FOR DYNAMIC CHANGES (E.G., CANCELLATIONS).
- FAIRNESS-AWARE OPTIMIZATION TO MINIMIZE STUDENT STRESS.

THE CURRENT IMPLEMENTATION ALIGNS WITH BEST PRACTICES BY INCORPORATING ELITISM, HYBRID DIVERSITY METHODS, AND PARALLEL EVALUATION, DEMONSTRATING THE CONTINUED RELEVANCE OF GAS IN SOLVING EXAM TIMETABLING PROBLEMS.

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