Evaluation of Scheduling Optimization Algorithms applied to Remote Sensing Satellites

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Agenda

- Constraint Based Search Concepts
- Search Optimization Approaches
- Constructive Approaches
- Stochastic Approaches
- Relevance to Satellite Tasking
- Satellite Model
- Dataset Characteristics
- Implementation Notes
- Algorithm Evaluations
- Conclusions
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Constraint Based Search Concepts

- Assigns a set of parameters with certain values for a given domain that satisfies a set of known constraints
- Constraint Satisfaction Problem (CSP)
  - Solved when a candidate satisfying the constraints is found
  - e.g. Map Coloring
- Constraint Optimization Problem
  - Not solved as soon as a candidate satisfies constraints
  - May not be possible to entirely satisfy constraints
  - Multiple candidates satisfy, but are not equally desirable
  - e.g. Traveling Salesman

Search Optimization Approaches

- Brute force search is the only deterministic approach for constraint based search.
- Not practical, the problem space scales factorially.

- Other approaches, reduce the search space to find a “very good” solution.
- All are nondeterministic.
- Two main categories
  - Constructive
  - Stochastic.

Search Optimization Approaches

- Constructive
  - Assigns one parameter a value at a time
    - May use heuristics to choose which parameter and value
    - May evaluate partial solution in heuristics
  - Checks constraints
    - If constraints are met, another parameter is assigned a value
    - Otherwise the last parameter assignment is repealed

Search Optimization Approaches

- Stochastic
  - Assigns a complete set of random values to parameters
  - Evaluates if constraints are met by the candidate
  - Measures goodness of candidates against each other
  - Chooses a candidate solution to move forward with
  - Always has an upper bound on the number of candidate solutions that may be considered

Constructive Approaches

- Greedy Algorithms
  - Build partial solutions to maximize use of a resource
  - Involve weighting the choices, sorting, and choosing
  - Works best with discrete values that do not change as a consequence of the partial solution

Constructive Approaches

- Branch and Bound
  - Builds partial solutions in either a depth first manner or breadth first manner (branch)
  - At each step of building a partial solution, the next set of choices are pruned using heuristics (bound)
  - Uses backtracking whenever a partial solution does not meet constraints
  - May put limits on the amount of backtracking
  - May use some randomization on backtracking

Stochastic Approaches

- Hill Climbing
  - Simplest approach
  - Generates a random candidate solution
  - Compares it to the previous solution
  - Keeps the best of the two and steps forward
  - Tends to get trapped in local minima/maxima

Stochastic Approaches

- Simulated Annealing
  - Mimics the process of cooling a material with the intent of providing a strong internal structure
  - Follows a cooling schedule

  - Similar to hill climbing but occaisonally chooses a less desirable solution
  - Chooses worse solutions less often as it progresses through the cooling schedule
  - Slower cooling increases the search space
  - Is better at escaping local minima/maxima than hill climbing

Stochastic Approaches

- Genetic Algorithms
  - Propogate the best fitness based on past results
  - Generate a population of candidate solutions
  - Choose 2 candidates to produce next population of solutions
  - Encodes a candidate solution as a chromosome
  - Offspring are subject to mutation

Relevance to Satellite Tasking

- Imaging Regions of Interest (ROI) subject to constraints such as time windows.
- Desire to get the most value from imaging tasks.
- Satellite itself is complex with many constraints.
- Model complexity has significant effect on schedule optimization
- Need algorithms that deal with continuous time
- Request feasibility affected byits place in the overall order of requests

Satellite Model

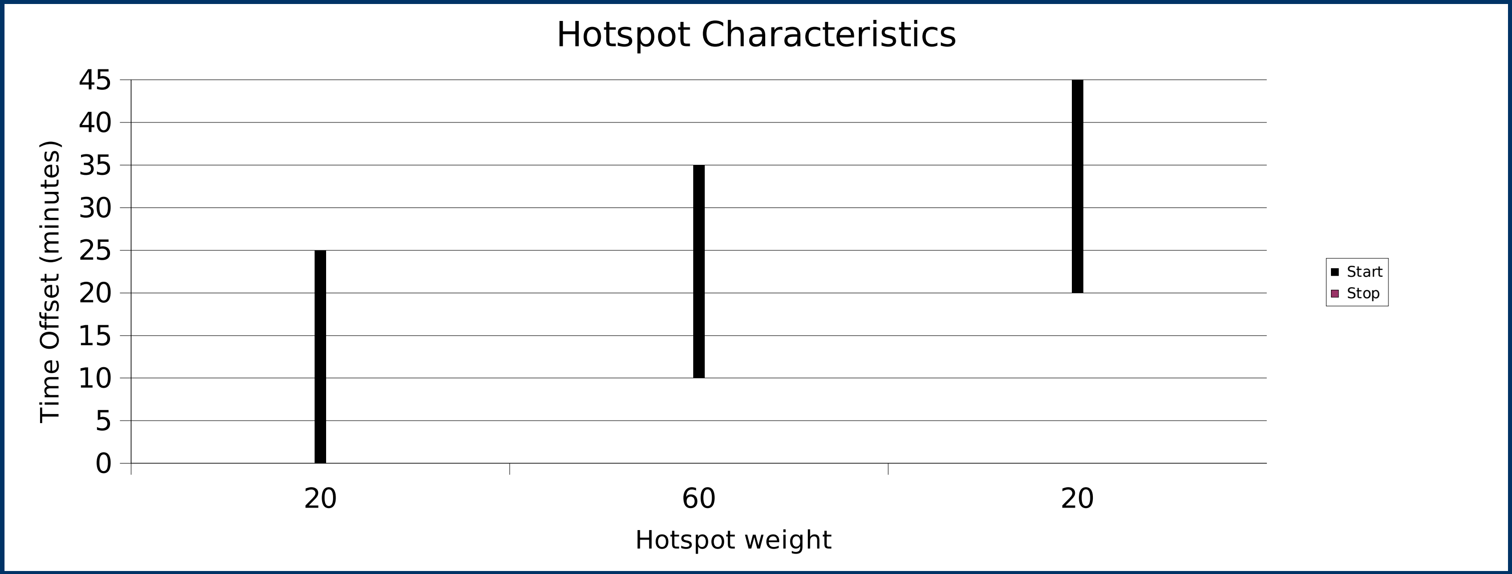
- Fixed Imaging Time
- Unlimited Storage
- No Groundtracking
- Sensor maneuvers
- 45 minute window

Satellite Model

- Planning
  - Idle Tasks
  - Slew Tasks
  - Sense Tasks
- For every imaging request the model's state is considered and a plan made to do only the above tasks that are needed to fulfill the request.

Dataset Characteristics

- Image Request included a value, time window constraint, and latitude/longitude target
- Dataset generation was random and persisted
- Sub-windows termed hotspots were used to create areas of higher contention between requests



Dataset Characteristics

- Same dataset used for all test results
- 175 image requests
  - 9 to 12 second window per request
  - 100 to 200 value
  - 0 to 10 degrees of slewing
- Schedule Fitness
  - Summation of the values of scheduled requests

Hardware

- CPU Type: PowerPC G4 (1.1)
- Machine Model: iBook G4
- Number Of CPUs: 1
- CPU Speed: 1.2 GHz
- L2 Cache (per CPU): 512 KB
- Memory: 256 MB
- Bus Speed: 133 MHz
- System Version: Mac OS X 10.3.9 (7W98)
- Kernel Version: Darwin 7.9.0

Implementation Notes

- Basic Scheduler
  - Takes a given set of requests and attempts to schedule them without changing the order.
  - Any request that is infeasible is discarded and the next is considered.
  - Used by all other schedulers

Implementation Notes

- Greedy Scheduler
  - Ability to sort image requests by
    - Window Start
    - Window Finish
    - Value
    - Latitude
  - Only sorts
  - Uses basic scheduler to get final schedule

Implementation Notes

- Genetic Algorithm
  - Used elitism
  - Used best schedule as first parent chromosome
  - Chose random second parent chromosome from statiscally weighted remaining population
  - Used basic scheduler to create the schedule for each chromosome

Algorithm Evaluations

- Genetic Algorithm
  - On its own achieved only 50% to 60% of the fitness of the greedy algorithm with 30,000 generations of 40 members each
  - Decided to initialize with a greedy sort
  - This tactic yielded the best results than either alone

Algorithm Evaluations

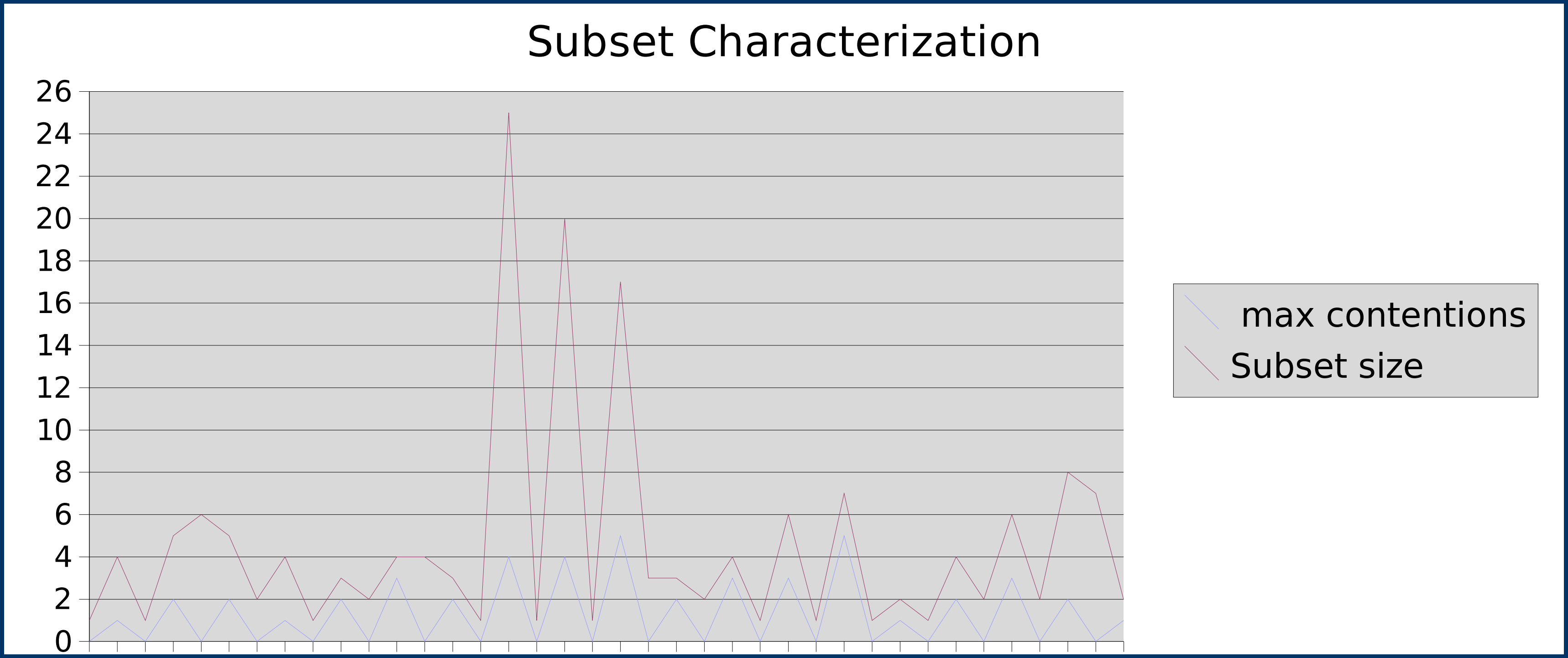
- Genetic Algorithm
  - Used 20,000 generations of 40 members each
  - Found that fitness was very sensitive to mutation
  - 1% mutation
  - Some subsets of the schedule have little tolerance to change
  - Difficult to know how change will affect the schedule
  - Prompted a look at another approach.

Algorithm Evaluations

- New Approach
- Consider map coloring
  - If a region has no neighbors (e.g. an island), it can be colored any way without affecting the overall solution.
- Consider the model
  - Unlimited storage
  - Only contention to consider was request time windows
  - Only subsets of requests with overlapping time windows needed to have their optimal order evaluated

Algorithm Evaluation

- Evaluation of the test dataset revealed that enough independent subsets existed to take advantage of



Algorithm Evaluation

- Composite Scheduler
  - Used the best features of
    - Greedy Algorithm
    - Genetic Algorithm
    - Exhaustive Search
  - Strategy
    - Greedy Sort the requests
    - Subsets of 2 to 10 requests use exhaustive search
    - Subsets of more than 10 requests use Genetic Algorithm
  - Exhibits some classical characteristics
    - Optimizing the subset optimizes the whole schedule
    - Divide and conquer
    - Could be parallelized

Algorithm Evaluation

- Greedy (Window Start)
  - 15714 score, 39msec, 1 run
- Greedy (Window Finish)
  - 15816 score, 11msec, 1 run
- Genetic (with window finish sort)
  - 16164 score (0.5% stdev), 581s ec(2.1% stdev)
  - 50 runs
- Composite (with window start sort)
  - 16376 score (44/50 runs), 16187score (6/50 runs)
  - 244 sec (1.1% stdev), 50 runs
- Composite (with window finish sort)
  - 16376 score (46/50 runs), 16187 score (4/50 runs)
  - 244 sec (1.8% stdev), 50 runs

Conclusions

- Larger space searches yield the best results
- Satellite scheduling is very sensitive to small permutations
- Greedy Algorithms provide good results fast but leave significant room for improvement
- Genetic Algorithms eventually outperform Greedy
- Genetic Algorithms may not produce a high yield of good candidates within a population
- Knowledge of model yielded best opportunities for improvement

Work since . . .

- Simulated Annealing and Hill Climbing
  - At the moment producing better results than genetic
- Model changes
  - More flexible constraints such as Limited Storage
- Planning changes
  - More flexible planning structure
- Request changes
  - Variable Sense time
- Future
  - More complex fitness score, groundtracking, sub-sense tasks, branch and bound

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