Artificial Intelligence Methods (G52AIM)

Dr Rong Qu

rxq@cs.nott.ac.uk

Tabu Search

Characteristics of SA (review)

- Random selection of a neighbouring solution
- Probabilistic acceptance of non-improving solutions;
- The best solution is recorded
  - Lack of memory of history of search;
  - All the information found during the search is lost;

Tabu Search

Proposed independently by Glover (1986) and Hansen (1986)

- "a meta-heuristic superimposed on another heuristic. The overall approach is to avoid entrapment in cycles by **forbidding or penalizing moves** which take the solution, in the next iteration, to points in the **solution space previously visited** (hence *tabu*)."

Tabu Search

- Accepts non-improving solutions **deterministically**
  - in order to escape from local optima (where all the neighbouring solutions are non-improving)
  - by guiding a steepest descent local search (or steepest ascent hill climbing) algorithm

Tabu Search

- After evaluating a number of neighbourhoods, we accept the best one, even if it is low quality on cost function.
  - Accept worse move
- Uses of memory to
  - prevent the search from revisiting previously visited solutions;
  - explore the unvisited areas of the solution space;

Tabu Search

- Use past experiences to improve current decision making
  - By using memory (a “tabu list”) to prohibit certain moves - makes tabu search a **global** optimizer rather than a local optimizer
- TS vs. SA
  - Accept worse move
  - Selection of neighbourhoods
  - Use of memory

Uses of memory during the search?

- Is memory useful during the search?

- Intelligence needs memory!
- Information on characteristics of good solutions (or bad solutions!)

Uses of memory during the search?

- Tabu move – what does it mean?

  1. Not allowed to re-visit exact the same state that we've been before

     - Discouraging some patterns in solution: e.g. in TSP problem, tabu a state that has the towns listed in the same order that we've seen before.
     - If the size of problem is large, lot of time just checking if we've been to certain state before.

Uses of memory during the search?

- Tabu move – what does it mean?

  2. Not allowed to return to the state that the search has just come from
     - just one solution remembered
     - smaller data structure in tabu list
  3. Tabu a small part of the state
     - In TSP problem, tabu the two towns just been considered in the last move – search is forced to consider other towns

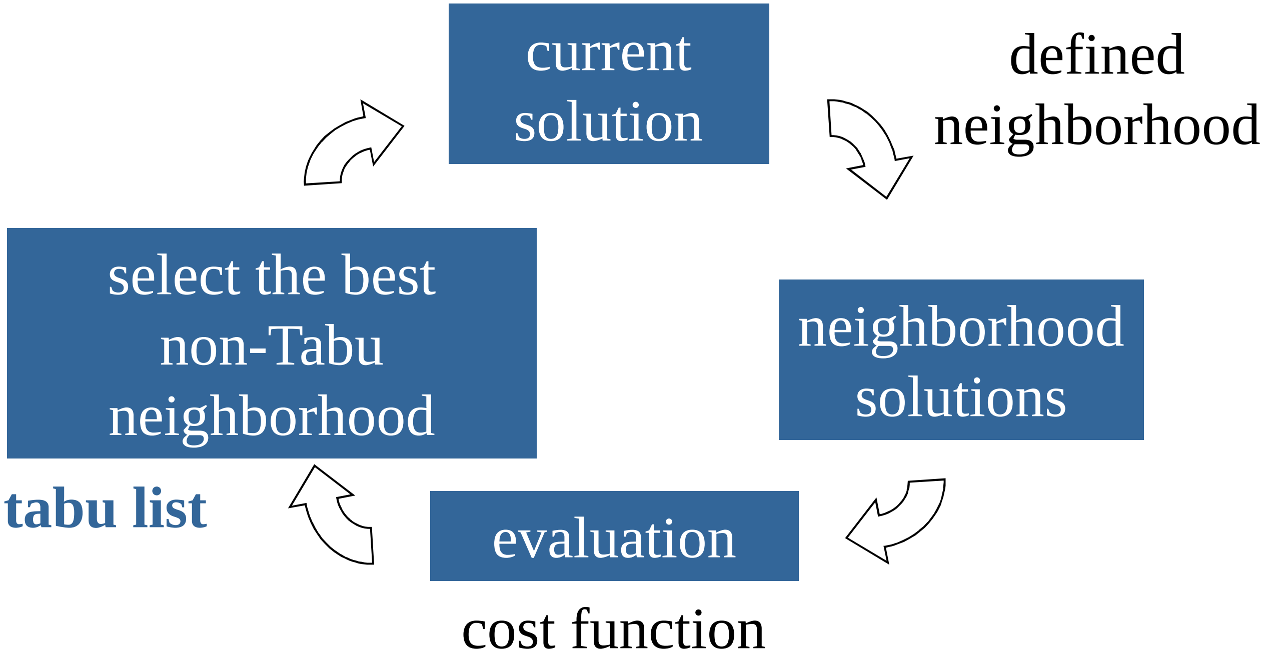
Dangers of memory

- Exhaustive usage of memory resources
  - Design of efficient data structures to record and access the recorded data efficiently;
    - Hash table
    - Binary tree
- Memorising information which should not be remembered

Dangers of memory

- Collecting more data than could be handled
  - Clear understanding of which **attributes** of solutions are crucial;
  - Limited selection of attributes of solutions to be memorised;
  - Clear strategy on usage of information or their disposal when not needed;

Tabu Search



current solution

defined neighborhood

neighborhood solutions

evaluation

cost function

select the best non-Tabu neighborhood

tabu list

Tabu Search algorithm

Function TABU_SEARCH(*Problem*) **returns** a solution state

- **Inputs**:
  - *Problem*: a problem
- **Local Variables**
  - *Current*: a state
  - *Next*: a state
  - *BestSolutionSeen*: a state
  - *H*: a history of visited states

Tabu Search algorithm

```
Current = MAKE-NODE(INITIAL-STATE[Problem])
While not terminate
    Next = a highest-valued successor of Current
    If(not Move_Tabu(H, Next) or Aspiration(Next))
    then
        Current = Next
        Update BestSolutionSeen
        H = Recency(H + Current)
    Endif
End-While
Return BestSolutionSeen
```

Elements of Tabu Search

- Memory related – recency (How recent the solution has been reached)
  - Tabu List (short term memory): to record a limited number of attributes of solutions (moves, selections, assignments, etc) to be discouraged in order to prevent revisiting a visited solution;

Elements of Tabu Search

- Memory related – recency (How recent the solution has been reached)
  - Tabu tenure (length of tabu list): number of iterations a tabu move is considered to remain tabu;
    - List of moves does not grow forever – restrict the search too much: restrict the size of list
    - FIFO
    - Other ways: dynamic

Elements of Tabu Search

- Memory related – frequency
  - Long term memory: to record attributes of elite solutions to be used in:
    - Diversification: Discouraging attributes of elite solutions in selection functions in order to diversify the search to other areas of solution space;
    - Intensification: giving priority to attributes of a set of elite solutions (usually in weighted probability manner)

Elements of Tabu Search

- If a move is good, but it's tabu-ed, do we still reject it?
- Aspiration criteria: accepting an improving solution even if generated by a tabu move
  - Similar to SA in always accepting improving solutions, but accepting non-improving ones when there is no improving solution in the neighbourhood;

Exercise: TS for TSP

- What neighbourhood we use
  - swap two cities
- What constitute a tabu list
  - Tabu **all** or part of the states visited before
  - Tabu the affected cities in the last (few) move(s)
  - Tabu key attributes in the last (few) move(s)
  - These are very different!!
    - "tabu a entire state" is rarely (never?) used
    - "tabu elements/attributes in the last moves" is very common

Example: TS for TSP

- Short term memory
  - Maintain a list of *t* towns and prevent them from being selected for consideration of moves for a number of iterations;
  - After a number of iterations, release those towns by FIFO

Example: TS for TSP

- Long term memory
  - Maintain a list of *t* towns which have been considered in the last *k* best (worst) solutions
  - encourage (or discourage) their selections in future solutions
  - using their frequency of appearance in the set of elite solutions and the quality of solutions which they have appeared in our selection function

Example: TS for TSP

- Aspiration
  - If the next moves consider those moves in the tabu list but generate better solution than the current one
  - Accept that solution anyway
  - Put it into tabu list

Tabu Search Pros & Cons

- Pros
  - Generated generally good solutions for optimisation problems compared with other AI methods
- Cons
  - Tabu list construction is problem specific
  - No guarantee of global optimal solutions

SA vs. TS

	SA	TS
No. of neighbours considered at each move	1	n
Accept worse moves? How?	Yes by P = exp^(-c/t)	Yes, the best neighbour if it is not tabu-ed
Accept better moves?	Always	Always (aspiration)
Stopping conditions	T = 0, or At a low temperature, or No improvement after some iterations	Certain number of iterations, or No improvement after some iterations

Learning Objectives

- Basics of Tabu Search
  - Use of memory in search: tabu of attributes rather than states
  - Tabu tenure
  - Tabu Search: algorithm, elements
  - TS vs. SA
- Application of Tabu Search
  - Be able to implement TS to solve optimization problems, including the one in your coursework

References

- Glover, F. (1986). Future Paths for Integer Programming and links to artificial intelligence. Computers and Operations Research 13: 533-549.
- Hansen, P. (1986) The steepest ascent mildest descent heuristic for combinatorial programming, Congress on Numerical Methods in Combinatorial Optimization, Capri, Italy.
- Glover, F., Laguna, M. 1998. *Tabu Search*. Kluwer Academic Publishers