ANA: Anytime Nonparametric A**

AAAI Conference, 2011

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Outline

- Motivation
- Previous Work
- The Algorithm
- Improvements of ANA* Over ARA*
- Experimental Results
- Conclusion and Future Work

Previous Work: Foundations

- Dijkstra’s Algorithm
  - Shortest path from s_{start} to s_{goal} with non-negative edges
  - Maintains g(s), minimum cost so far
- A*
  - Adds heuristic to Dijkstra’s
  - Admissible h(s) guarantees optimality, consistent h(s) guarantees cycle-free search
- Weighted A*
  - $f(s) = g(s) + \varepsilon * h(s)$
  - $\varepsilon \geq 1$, bounds optimality
  - Raising ε trades optimality for speed

*Previous Work: Anytime A**

- Anytime Heuristic Search (AHS)
  - Continues search after solution found
  - Intermediate upper bound: G
  - Intermediate lower bound: $\min_{s \in OPEN}\{g(s)+h(s)\}$
- Anytime Repairing A* (ARA*)
  - Decreases ε between results, updating f(s) values
  - Introduces another parameter
- Restarting Weighted A* (RWA*)
  - Restarts search when ε is decreased
  - Reuses best known g(s) values for states

The ANA Algorithm*

- ANA*()
  $G \leftarrow \infty$; $E \leftarrow \infty$; $OPEN \leftarrow \emptyset$;
  $\forall s: g(s) \leftarrow \infty$; $g(s_{start}) \leftarrow 0$
  Insert s_{start} into OPEN with
  key $e(s_{start})$
  while $OPEN \neq \emptyset$ do
  IMPROVESOLUTION()
  Report current E-suboptimal
  solution
  Update keys e(s) in OPEN
  and prune if $g(s)+h(s) \geq G$

- IMPROVESOLUTION()
  while $OPEN \neq \emptyset$ do
  $s \leftarrow \text{argmax}_{s \in OPEN}\{e(s)\}$
  $OPEN \leftarrow OPEN \setminus \{s\}$
  if $e(s) < E$ then
  $E \leftarrow e(s)$
  if ISGOAL(s) then
  $G \leftarrow g(s)$
  return
  for each successor s' of s do
  if $g(s)+c(s,s') < g(s')$ then
  $g(s') \leftarrow g(s)+c(s,s')$
  $pred(s') \leftarrow s$
  if $g(s')+h(s') < G$ then
  Insert or update s' in
  OPEN with key e(s')

The ANA Algorithm cont.*

- e(s) is the maximal ε for which $f(s) \leq G$
- e(s) bounds suboptimality
- G improves after each iteration

$$e(s) = \frac{G - g(s)}{h(s)}$$

ARA vs ANA**

- Requires parameters ε and Δε
- Starting ε must be finite
- Progress towards optimal solution is invariable
- If adapted to function like ANA*, f(s) keys would have to be updated for each change in ε

- Requires no parameters
- Starting G is infinite
- Progress towards optimal solution is the least possible improvement at each step
- e(s) keys only need to be updated when G is reduced

Experiments: Problems

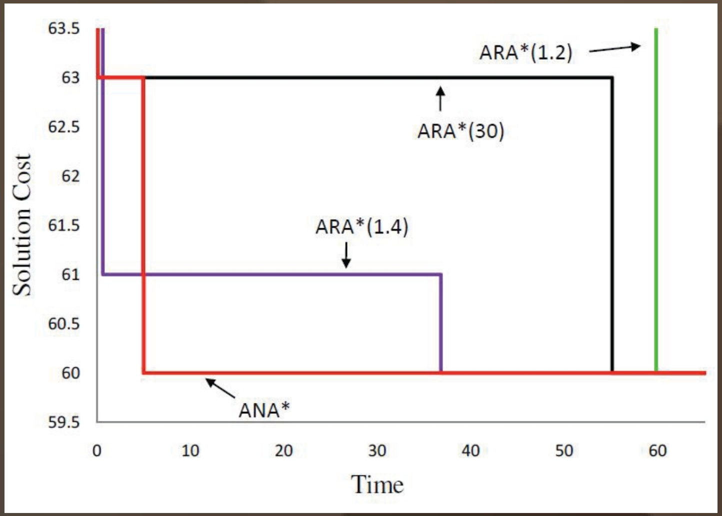
- Robot Arm: position arm to reach goal, avoiding obstacles
  - 6 or 20 degrees of freedom
  - action is a change in a joint's angle
  - $>3*10^6$ states for 6 DOF, $>10^{26}$ states for 20 DOF
- Gridworld: navigate from start to goal in an n x m grid
  - Grid 1: 100x1200 8-connected, obstacles, uniform move cost between cells sharing a side
  - Grid 2: 5000x5000 4-connected, no obstacles, move cost randomly chosen from [1,1000]
  - Grid 3: 5000x5000 4-connected, obstacles, move cost randomly chose from [1,1000]

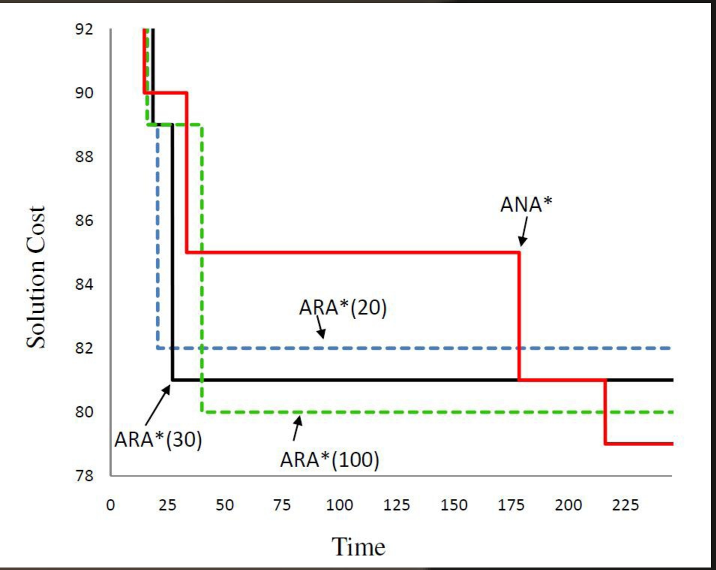
Experiments: Problems cont.

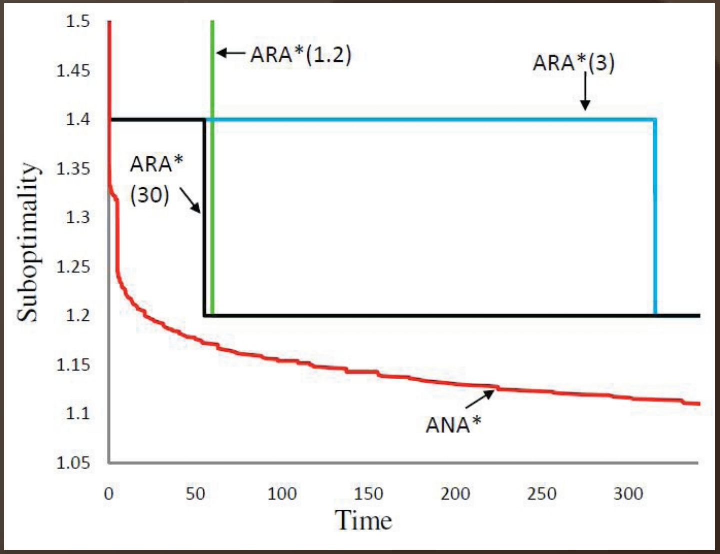
- Multiple Sequence Alignment: find lowest cost alignments of n proteins
    - n=5
    - gaps in a sequence cost 2
    - mismatched pairs cost 1

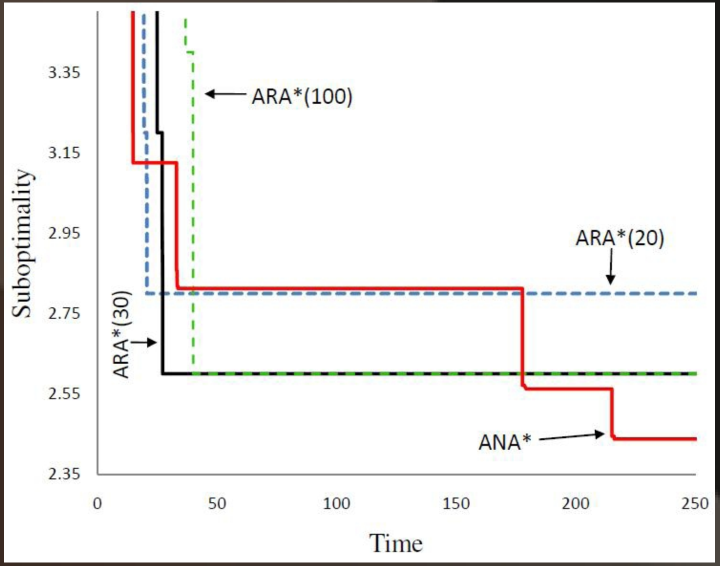
Experiments: Results-Robotic Arm

6 DOF vs 20 DOF



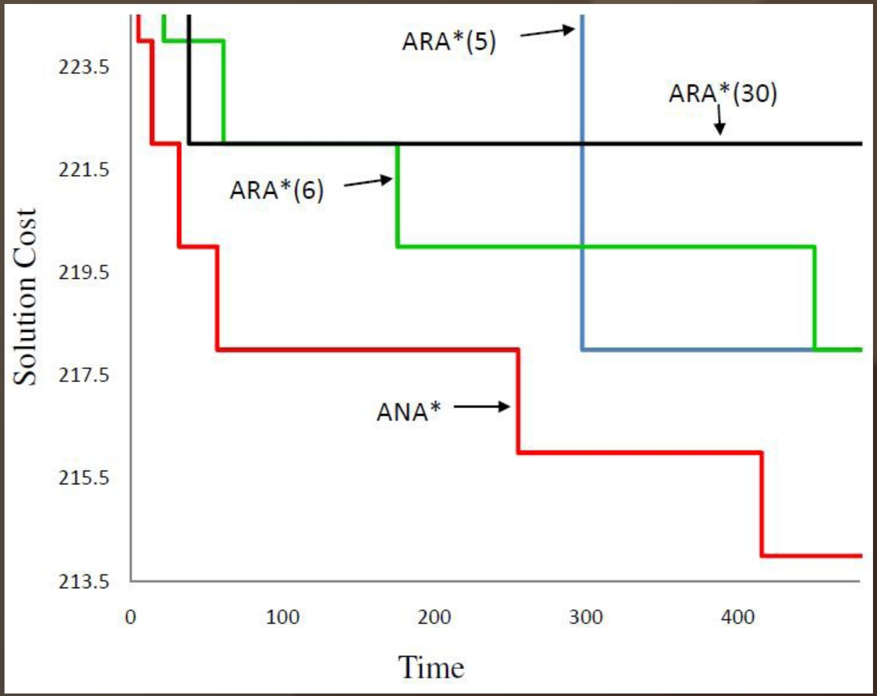


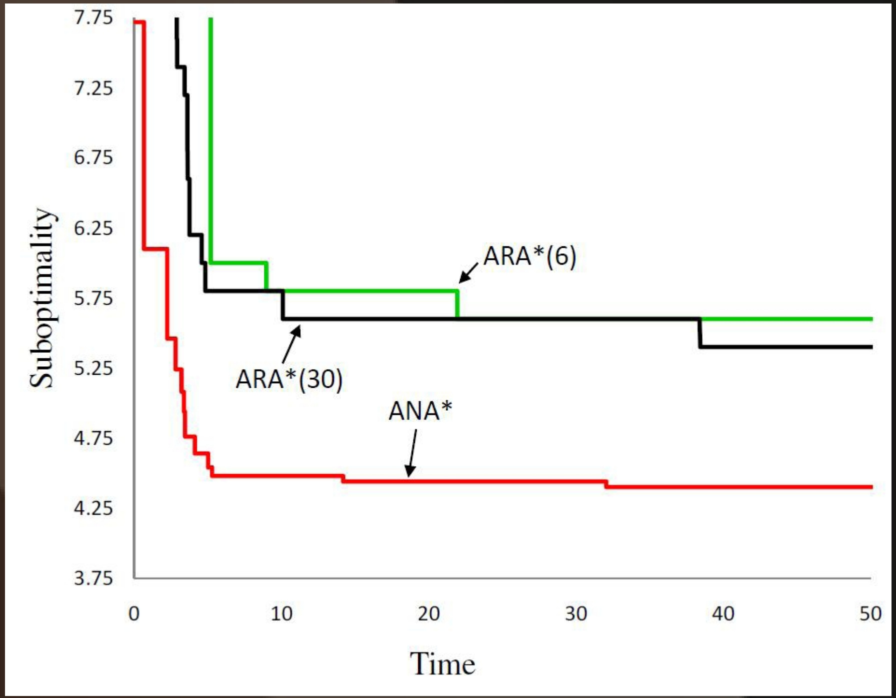




Experiments: Results-Robotic Arm

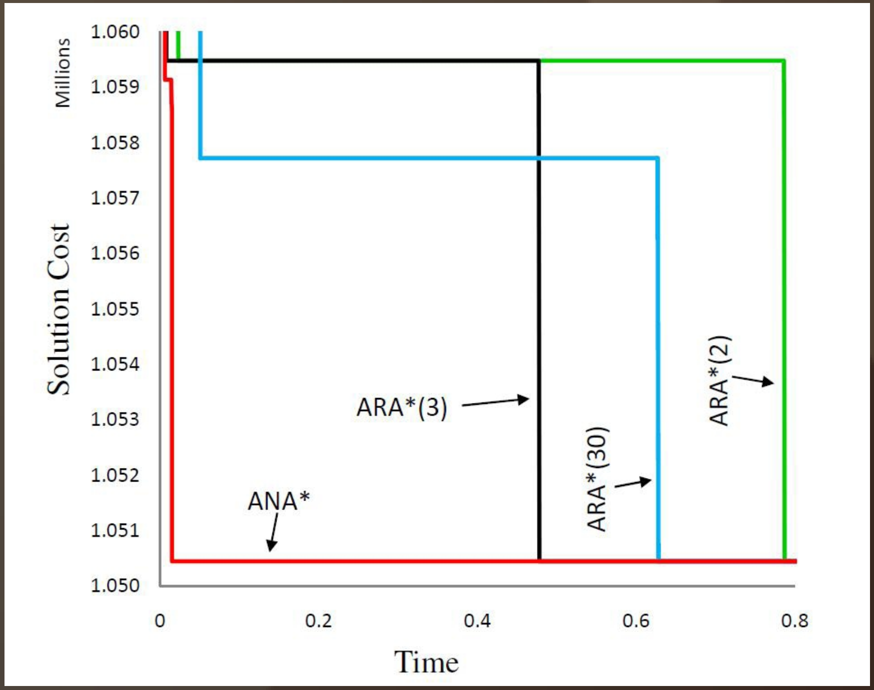
6 DOF, non-uniform cost

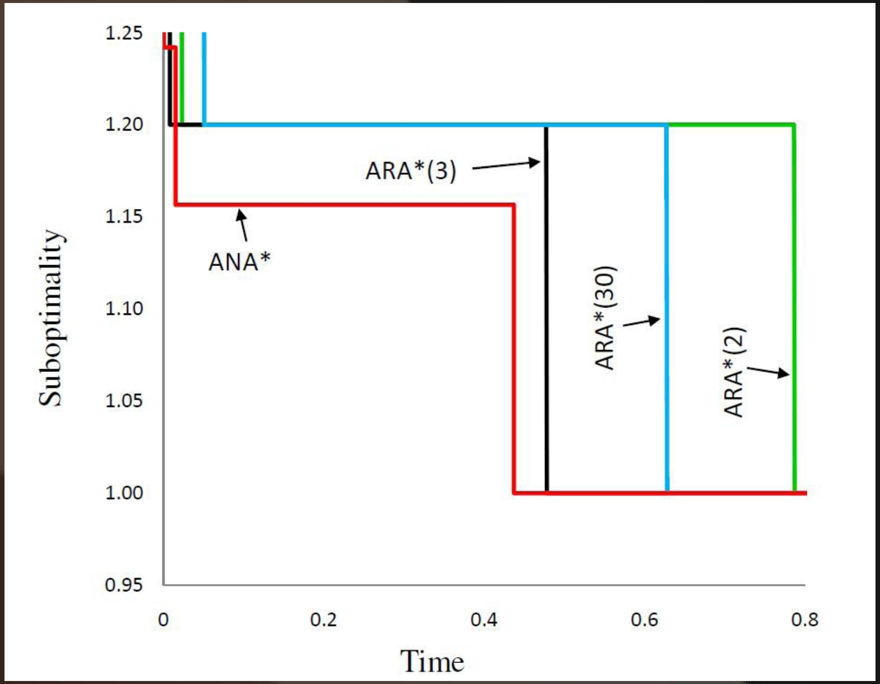




Experiments: Results-Gridworld

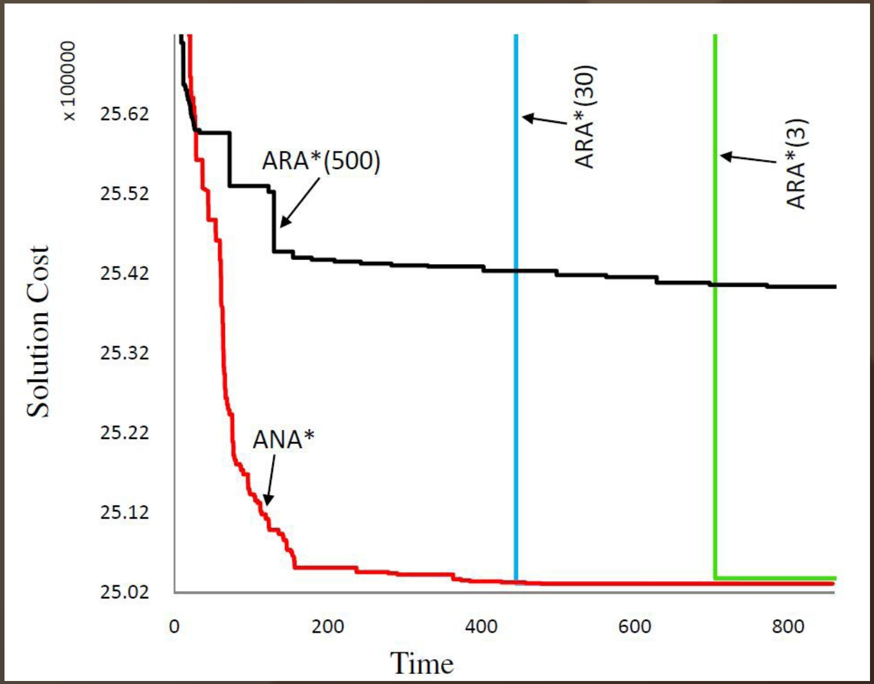
100x1200 with obstacles, uniform cost

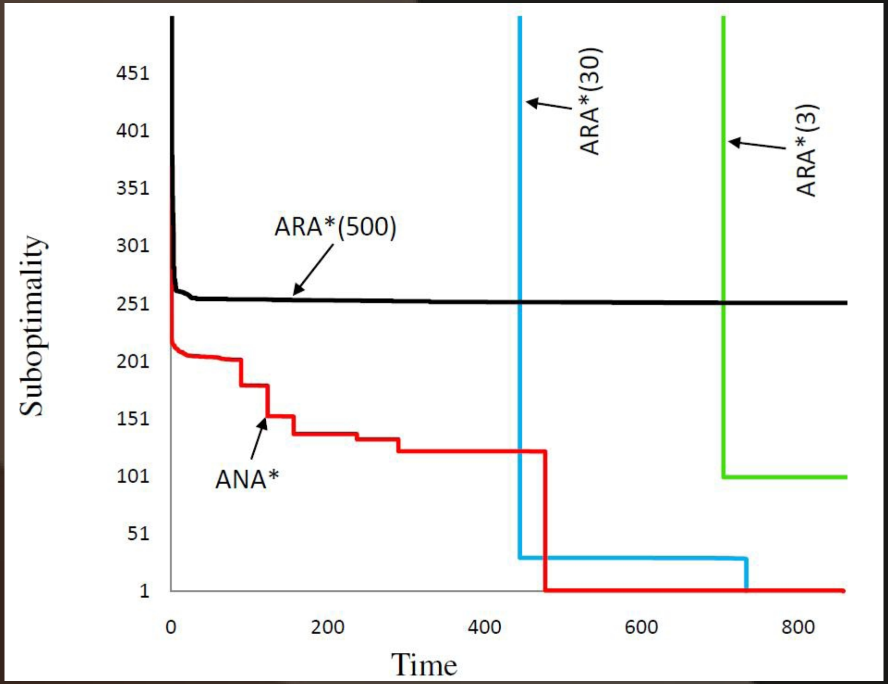




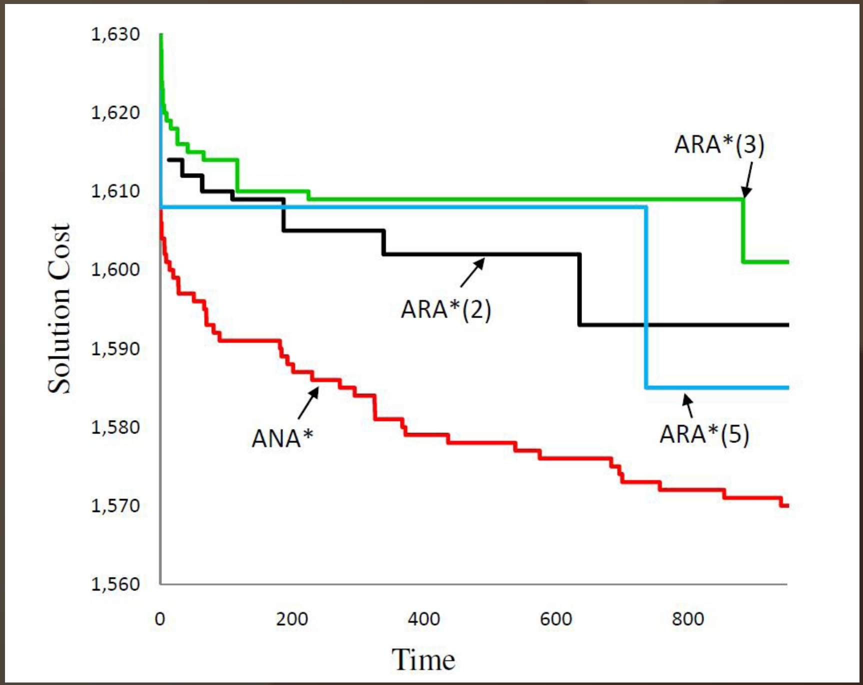
Experiments: Results-Gridworld

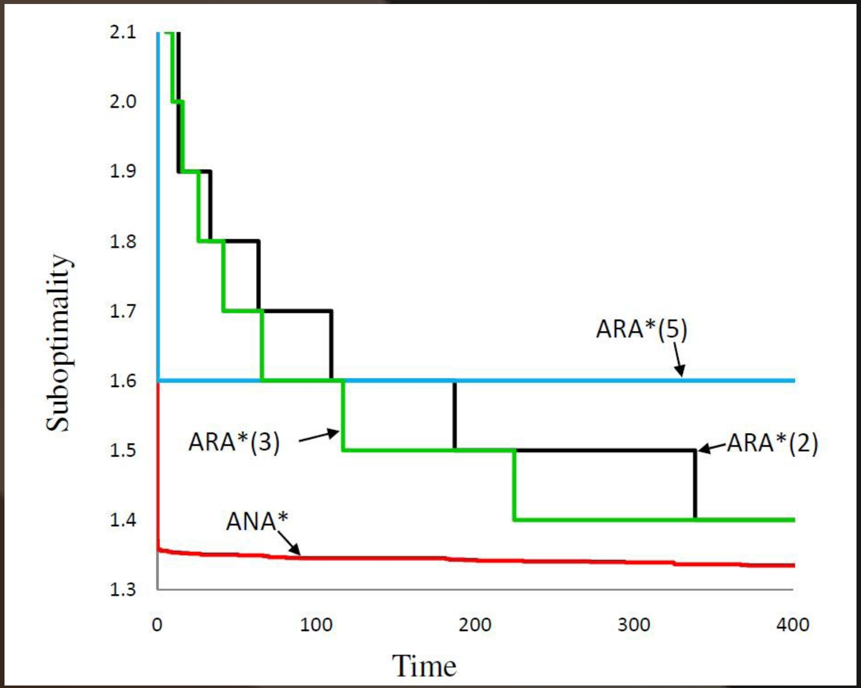
5000x5000 without obstacles, random cost





Experiments: Results-MSA





Conclusion and Future Work

- ANA* expands upon ARA*
- ANA* outperforms existing anytime A* algorithms both analytically and experimentally
- Future research in dynamic weight graph search

Citations

- Jur van den Berg, Rajat Shah, Arthur Huang, and Ken Goldberg, “ANA*: Anytime Nonparametric A*,” Association for the Advancement of Artificial Intelligence: Annual Conference (AAAI). San Francisco, CA. August 2011.
- Jur van den Berg, Rajat Shah, Arthur Huang, and Ken Goldberg, “*ANA* Technical Report,*” February 2011.
- Maxim Likhachev, Geoff Gordon and Sebastian Thrun, "ARA*: Anytime A* with Provable Bounds on Sub-Optimality," Advances in Neural Information Processing Systems 16 (NIPS), MIT Press, Cambridge, MA, 2004.

Questions