Heuristic Search for Transfer Design

Background:
- Multibody systems are highly nonlinear and chaotic due to balance of forces from planets and moons.
- For “low energy” missions to orbit moons and small bodies, traditional methods are unable to provide reliable initial guesses to optimizers.

Central Concept: Approximate system with directed graph. Use to create a transfer skeleton.
- Partition domain into small regions. 1 region = 1 node
- Ballistic dynamics: Add directed edge from node X to node Y if region X flows into node Y. Weight = nominal control cost
- Impulsive maneuvers: Add directed edge between nodes with same position but with different energy levels or headings. Weight is minimum fuel cost between these pairs.
Using A* Search in Itinerary Selection

**Need for Heuristics:**

- For minimum fuel problem, cost of large impulse $\gg$ nominal coasting cost.
- Most important scenario: Orbit insertion from approach or higher orbit. Requires large drop in energy.
- Result w/ uninformed search: Search explores too many coasting nodes before considering necessary impulsive maneuvers.

**Simplified Energy Heuristic:**

- Between any two energy levels with a given compact domain and moon radius there is a calculable most efficient maneuver cost.  
  \[ \text{This is a } \text{tangential} \text{ maneuver at the highest velocity and/or lowest potential} \]
- **Heuristic as rule relaxation:** It assumes this most efficient maneuver is possible everywhere in the domain.
- This makes $h(n)$ a simple (consistent) function of energy($n'$) and energy(goal).
- Heuristic steers search towards correct energy.
Applying the Search Results

**Impact of the heuristic:** Decrease in search times from ~2-3 minutes to ~1-10 seconds in simple test system.

**Example in context:** Search provides region and maneuver sequence. This allows for selection of arcs from a table which feed into a Sequential Convex Programming process to restore continuity and optimize.

(Note: the actual partition is 4D and contains ~9,000 regions per energy)